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Research at Harwell and Berkeley

On-load refuelling problems

Belgrade electronics conference

Safety in research reactors

August 1961 monthly 3/6

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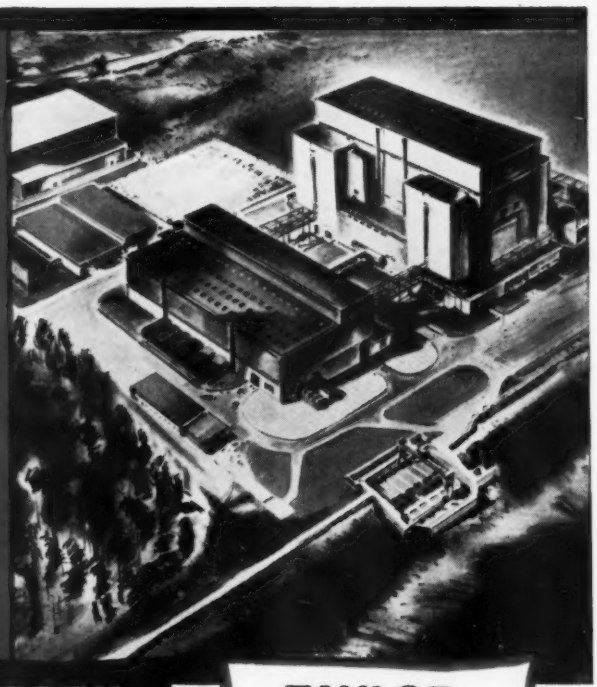

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COVER PICTURE

Beyond Berkeley's No. 1 reactor are the new CEGB nuclear research laboratories.

Nuclear Power

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SPECIAL FEATURES

7th UKAEA annual report
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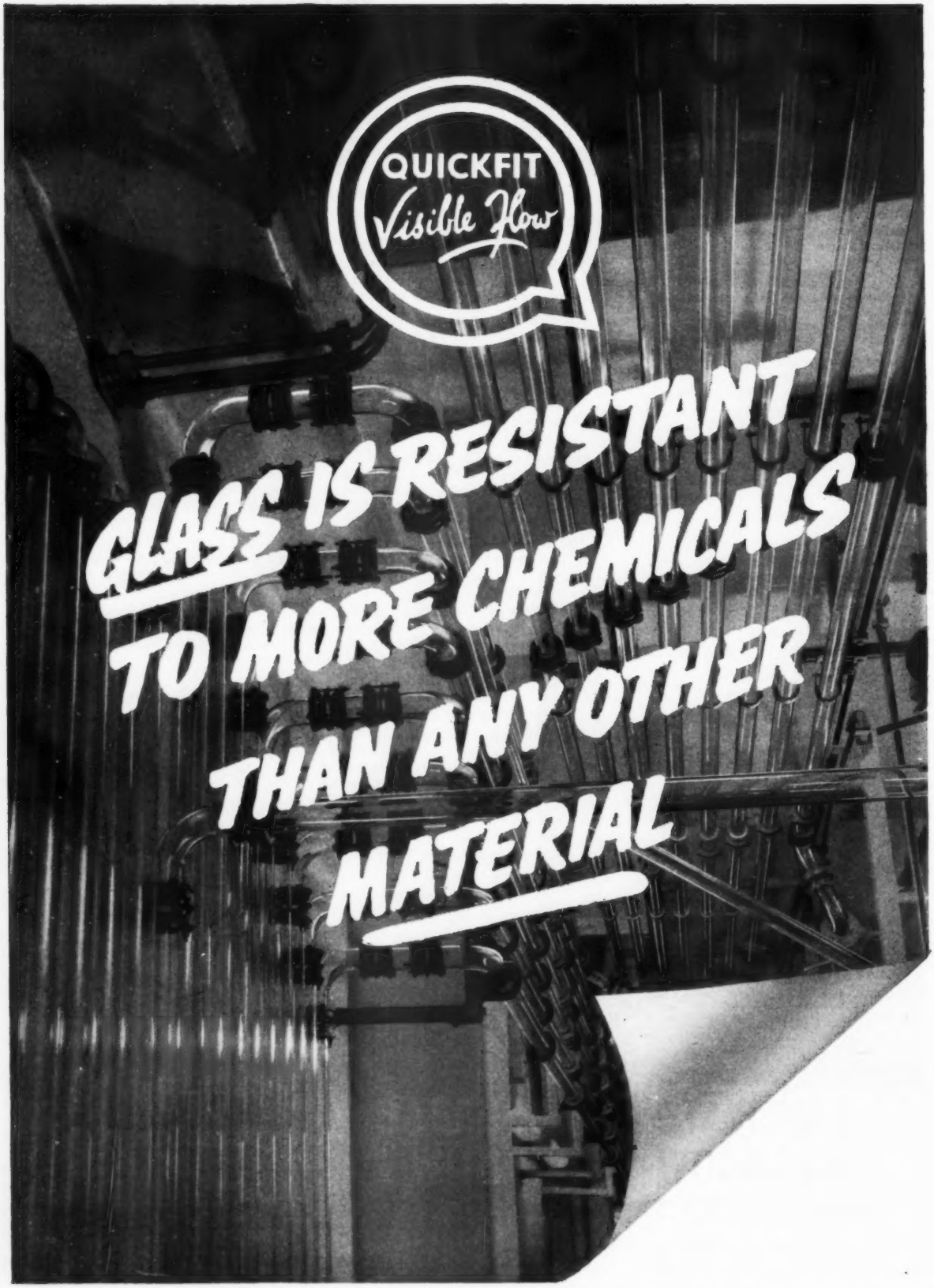

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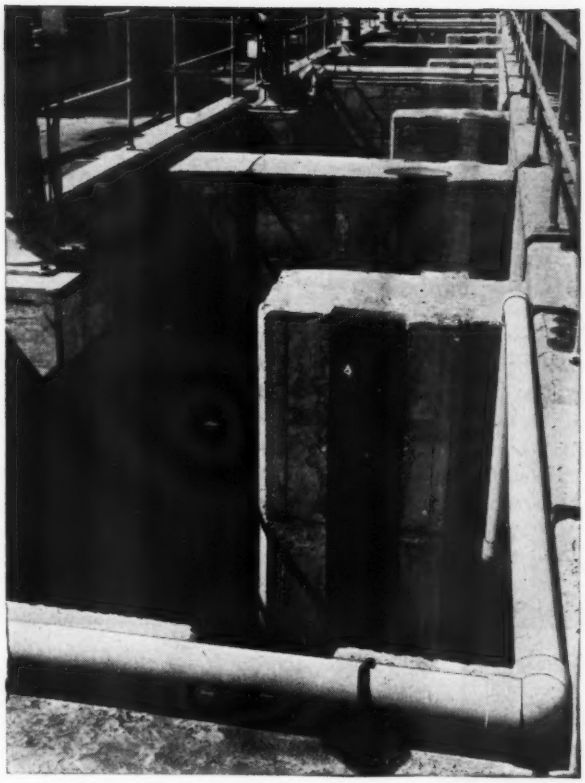
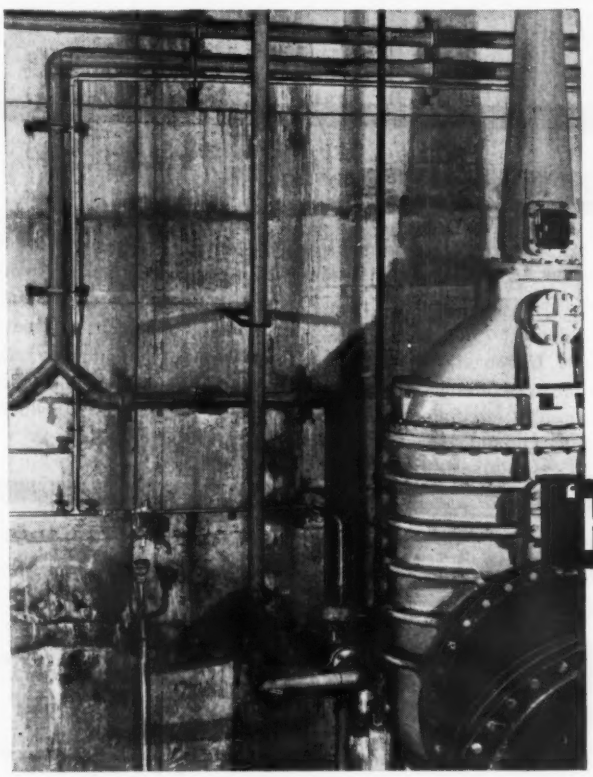


3″ nom. bore 'Durapipe' K made from 'Kralastic' A.B.S. copolymer by Durapipe and Fittings Ltd., of West Drayton, installed in the chlorination plant at the C.E.G.B. Marchwood Power Station. This plant was supplied and engineered by Wallace and Tiernan, Chiswick, London W.4.



'Kralastic' solves two corrosion problems at once at Marchwood Power Station

These pipes at the Central Electricity Generating Board's Marchwood Power Station have to resist two forms of chemical corrosion. They carry heavily chlorinated water that is injected in small doses into the cooling system, and are constantly subjected on the outside to the attack of corrosive elements from the atmosphere (admittedly minute but nevertheless potent), aggravated by the excess of moisture associated with cooling systems. Under these two forms of attack conventional metal pipes lasted less than a year. But these 'Durapipe' K pipes have been installed since 1956 and are still in good condition – because they are made from 'Kralastic' A.B.S. copolymer. 'Kralastic' is highly resistant to this type of corrosion, and is also extremely tough, rigid and very light in weight. If you would like more information about the 'Kralastic' range of copolymers and the Technical Service provided by I.C.I., your nearest I.C.I. sales office will be glad to help you.

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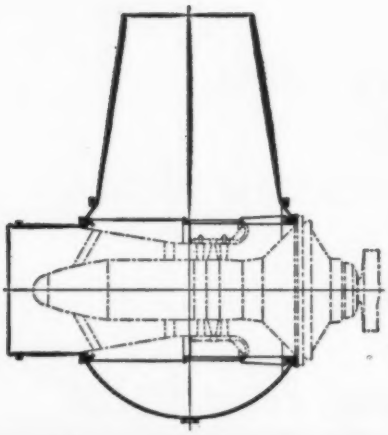
New thinking for Trawsfynydd



CO_2 CIRCULATORS

As every engineer knows, the thickness of plate required to contain a given pressure is halved if the vessel is spherical instead of cylindrical. It is odd—but nevertheless true—that it was not until our own engineers were confronted with the design of the CO_2 circulatory system for Trawsfynydd that the elementary principle was put into practice on large pressure pipework.
Besides halving the plate thickness spherical construction has other advantages. All welds are circular, can be prepared by machinery and are simple to X-ray.

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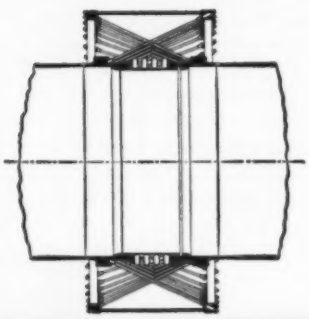

EXPANSION JOINTS

It is standard practice to take up the expansion of large diameter pipework by flexing at what are essentially hinged joints. These of course have to provide restraint against axial forces—over 1,000,000 lb. in the Trawsfynydd ducting. The usual solutions, an internal metal tongue or a hinged joint are heavy, cumbersome and, moreover, flexible in one direction only. The hinge we have devised is flexible in *all* directions, by elastic straining of the high-tensile steel, restraining rods. The circumferential pressure is taken by a metal bellows, faired internally by a floating sleeve.

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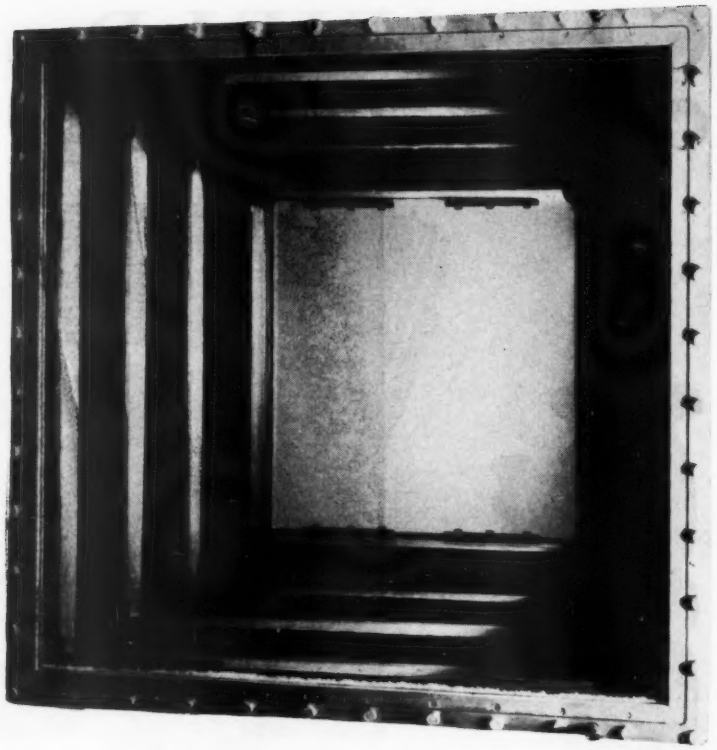

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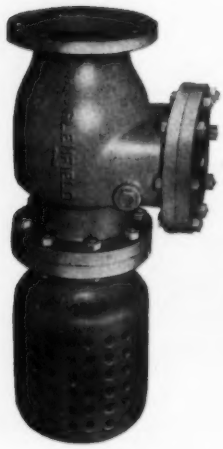

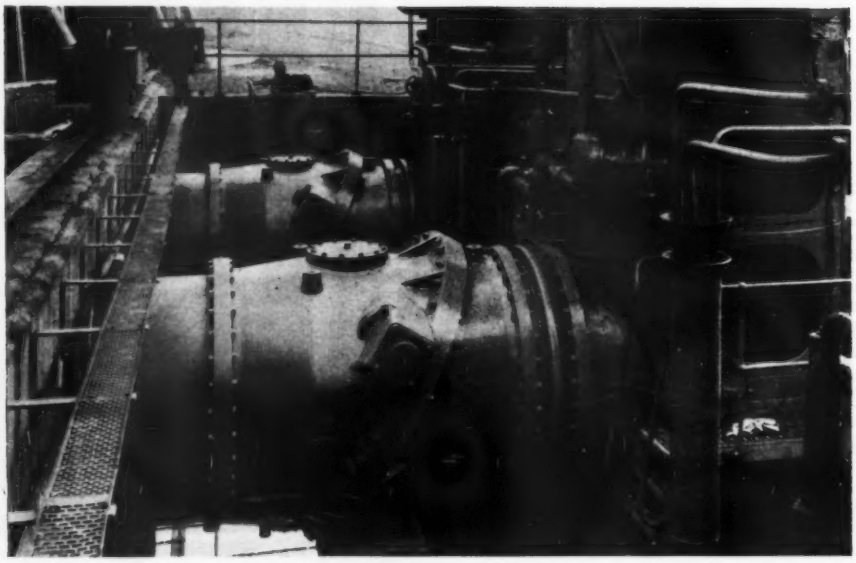

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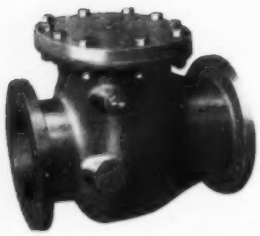

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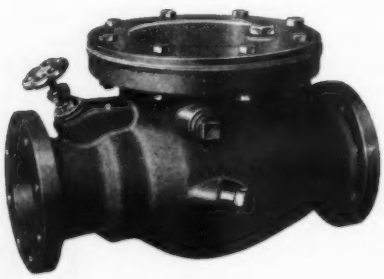

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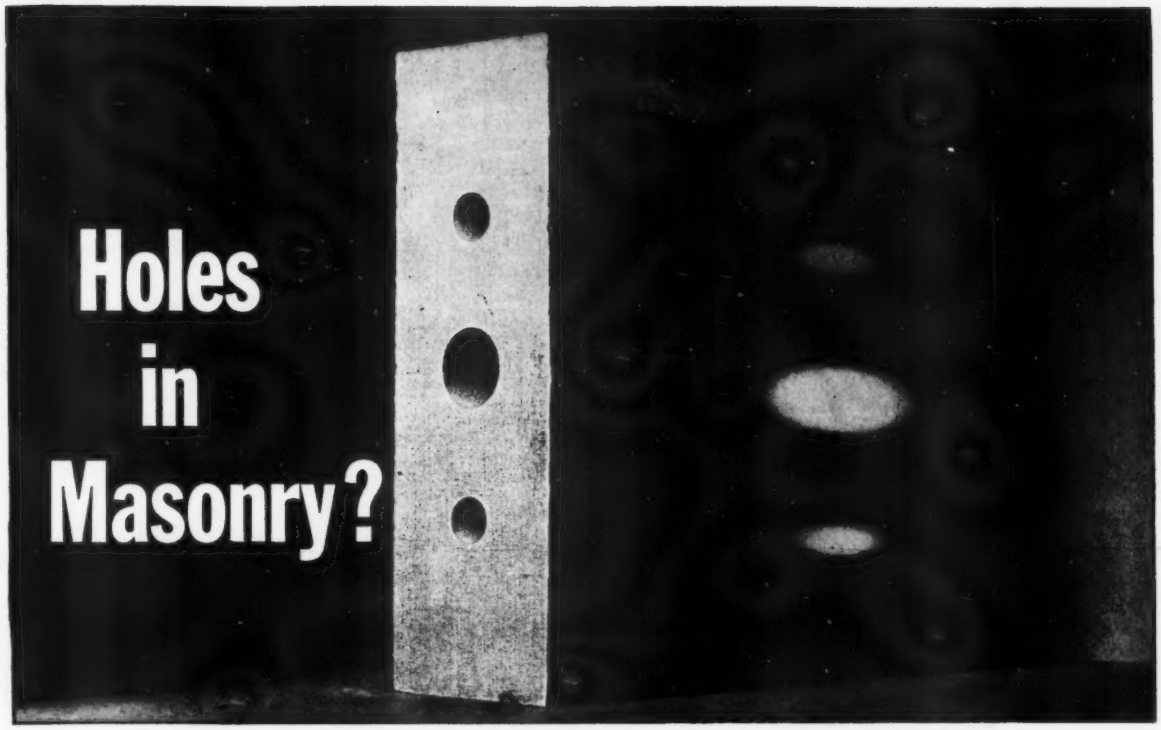

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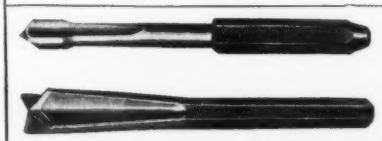

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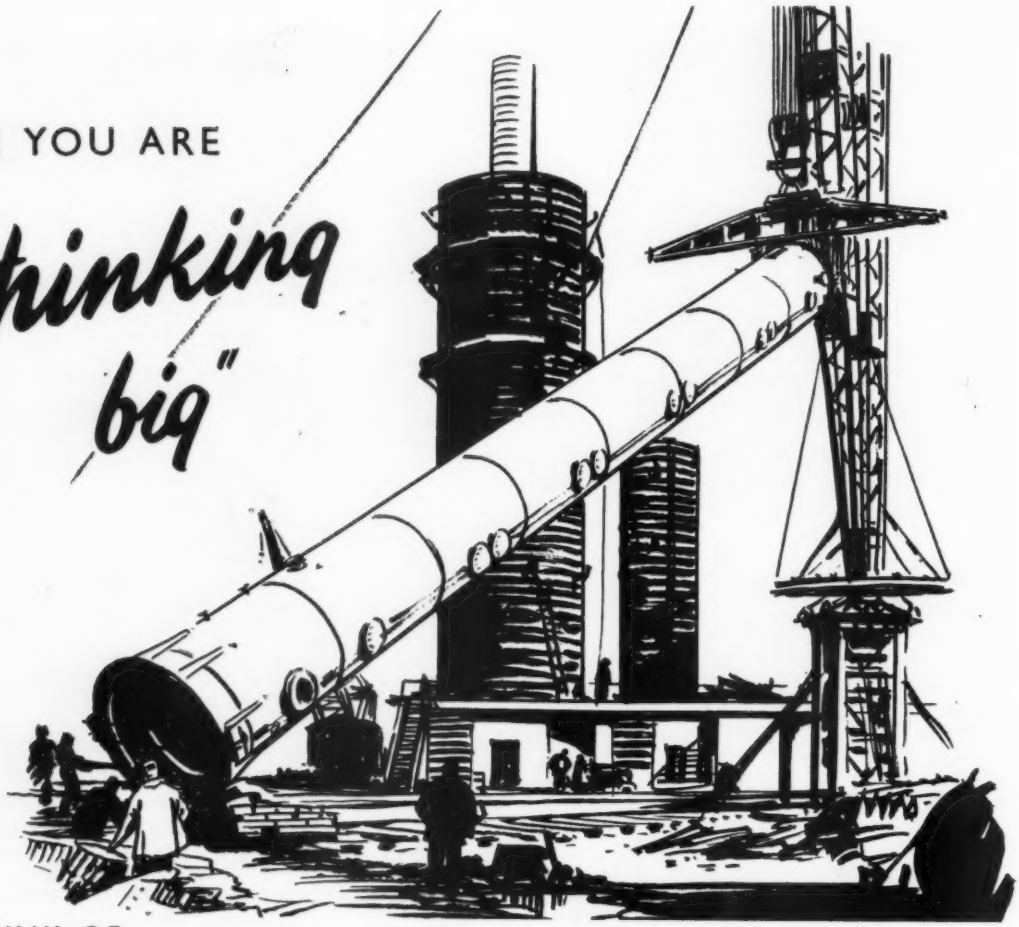

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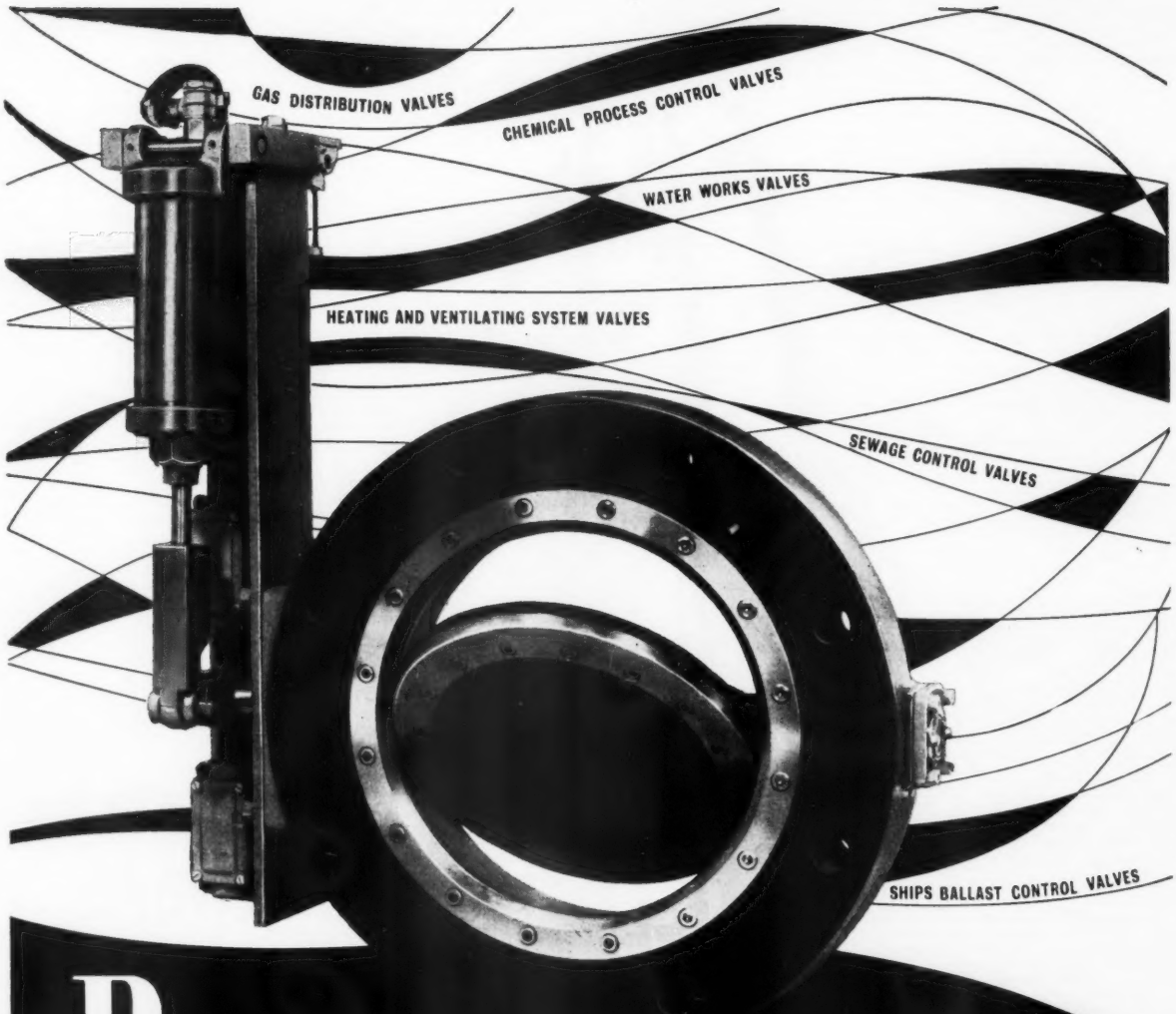

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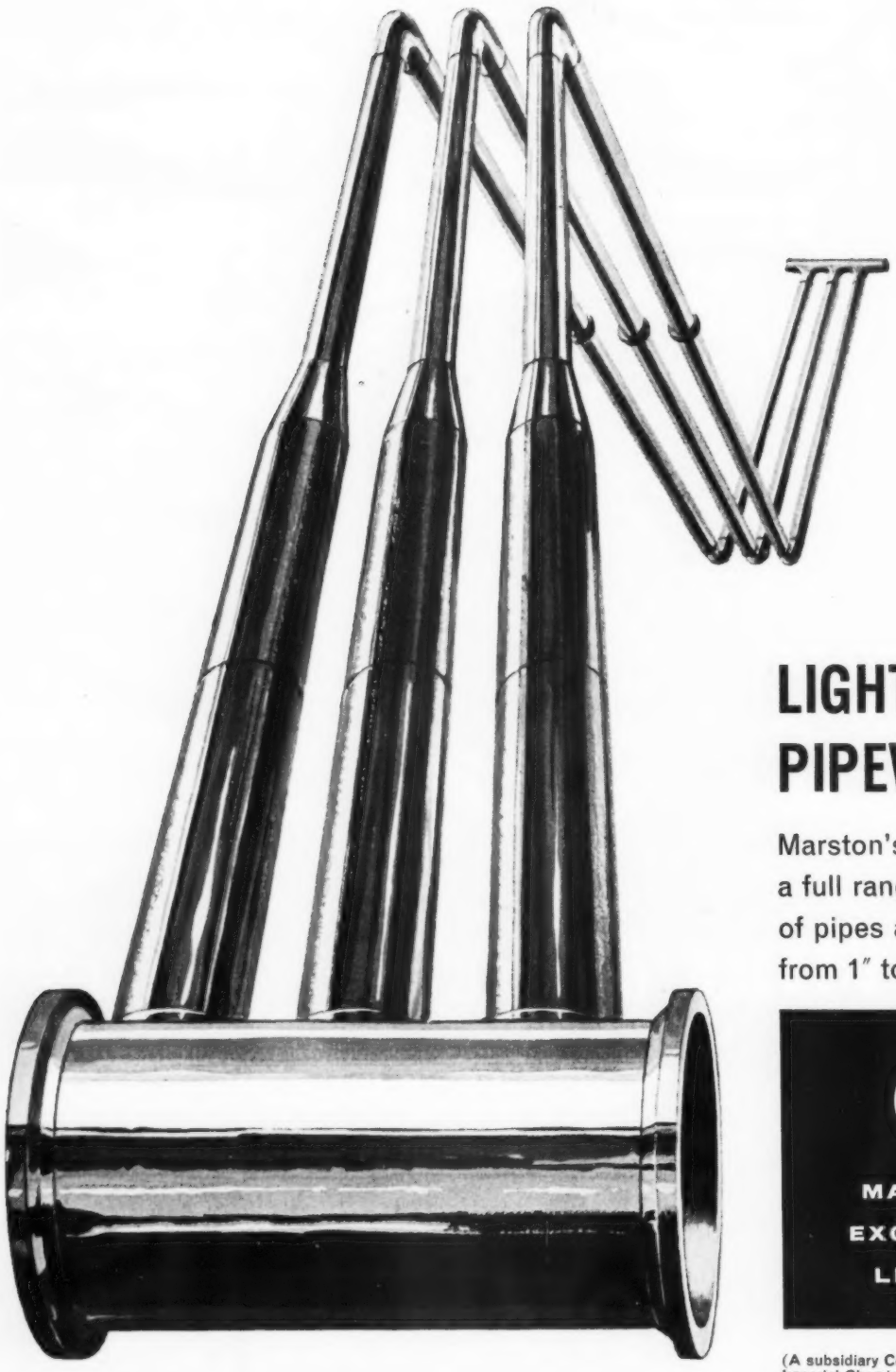

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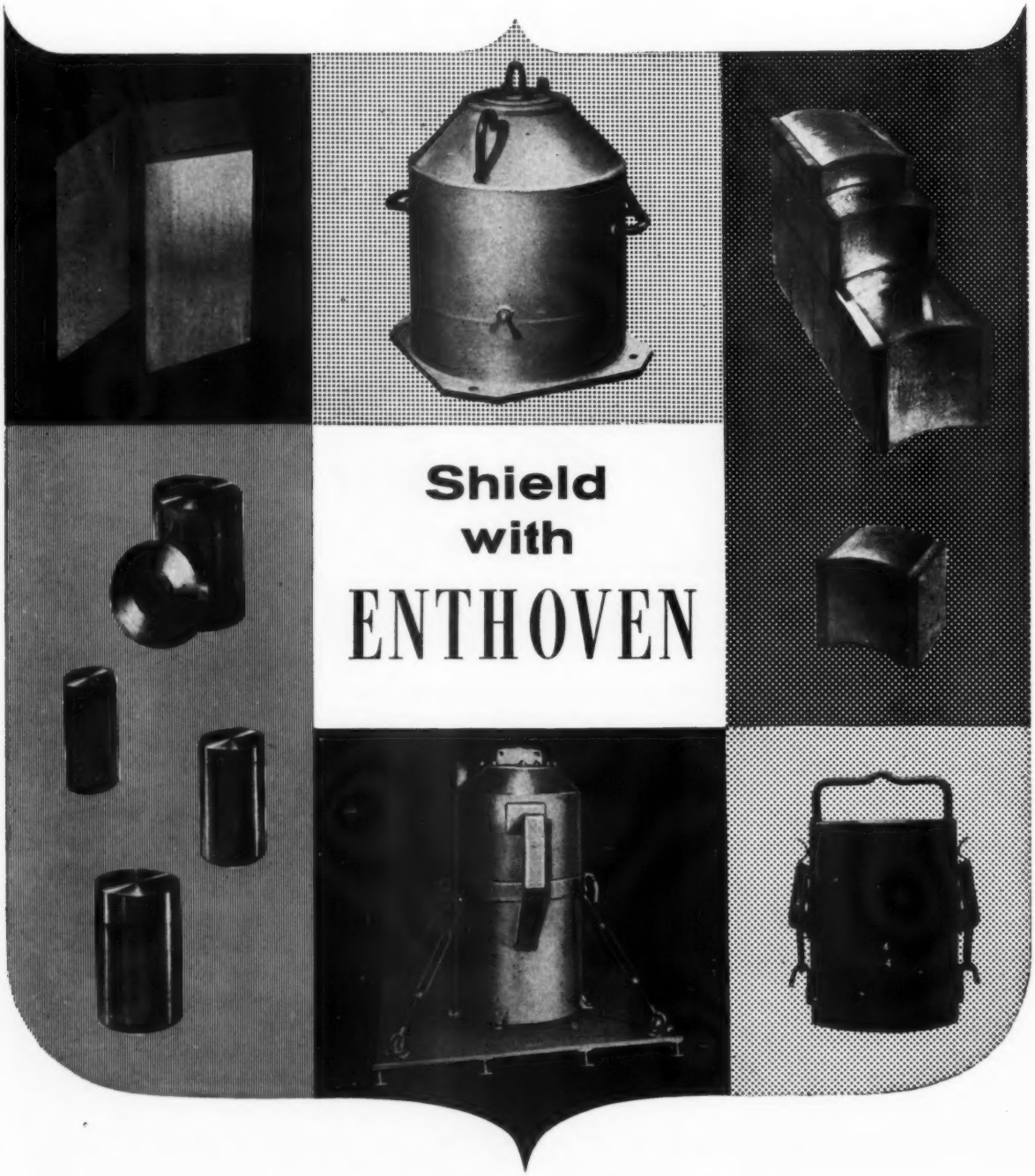

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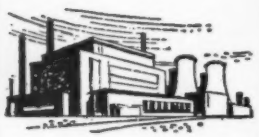

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74

. . . if I were to emigrate

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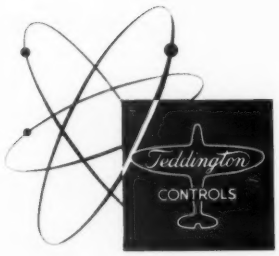

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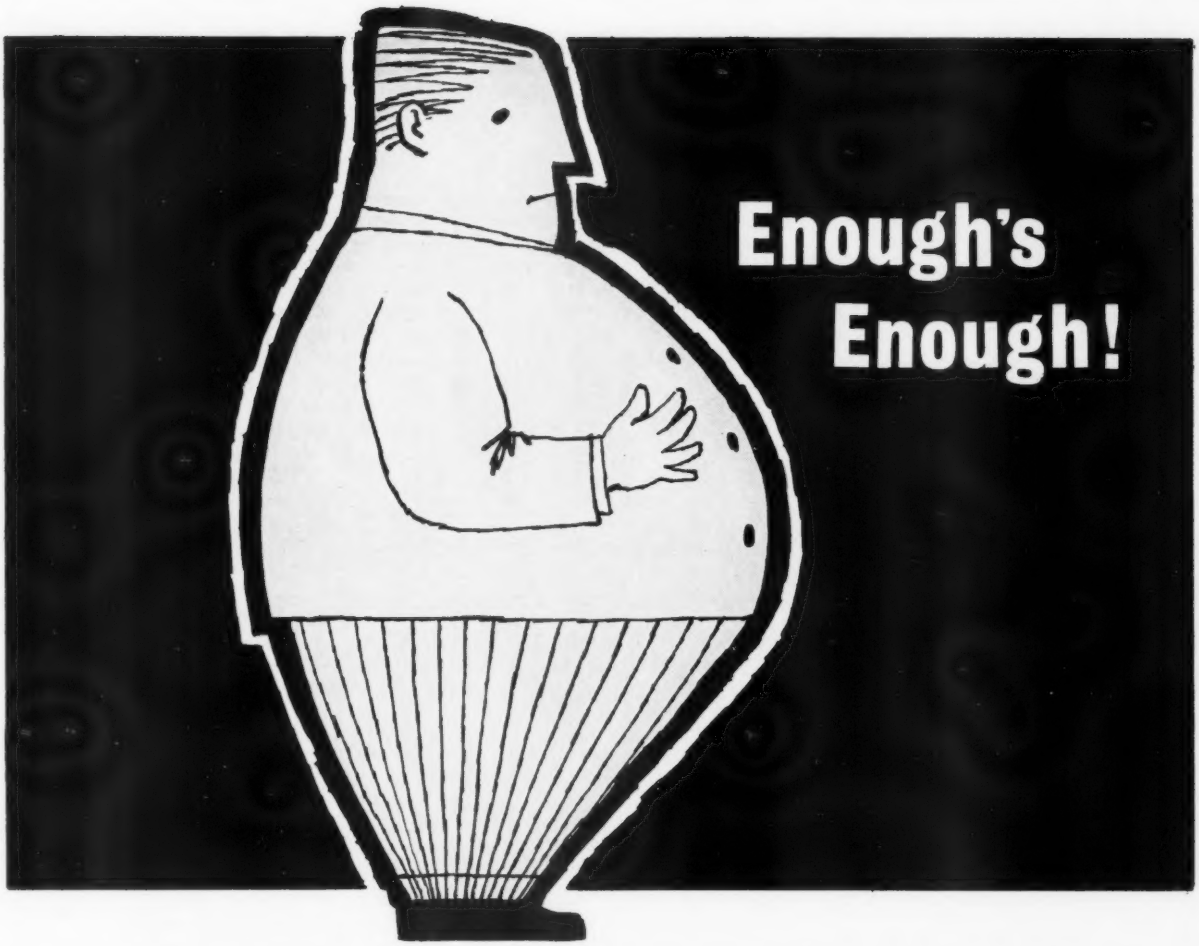
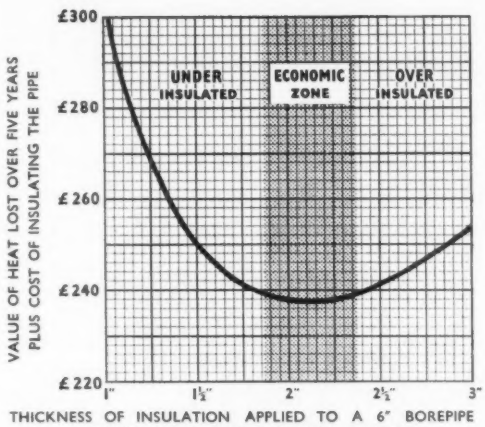


Economic thickness of insulation



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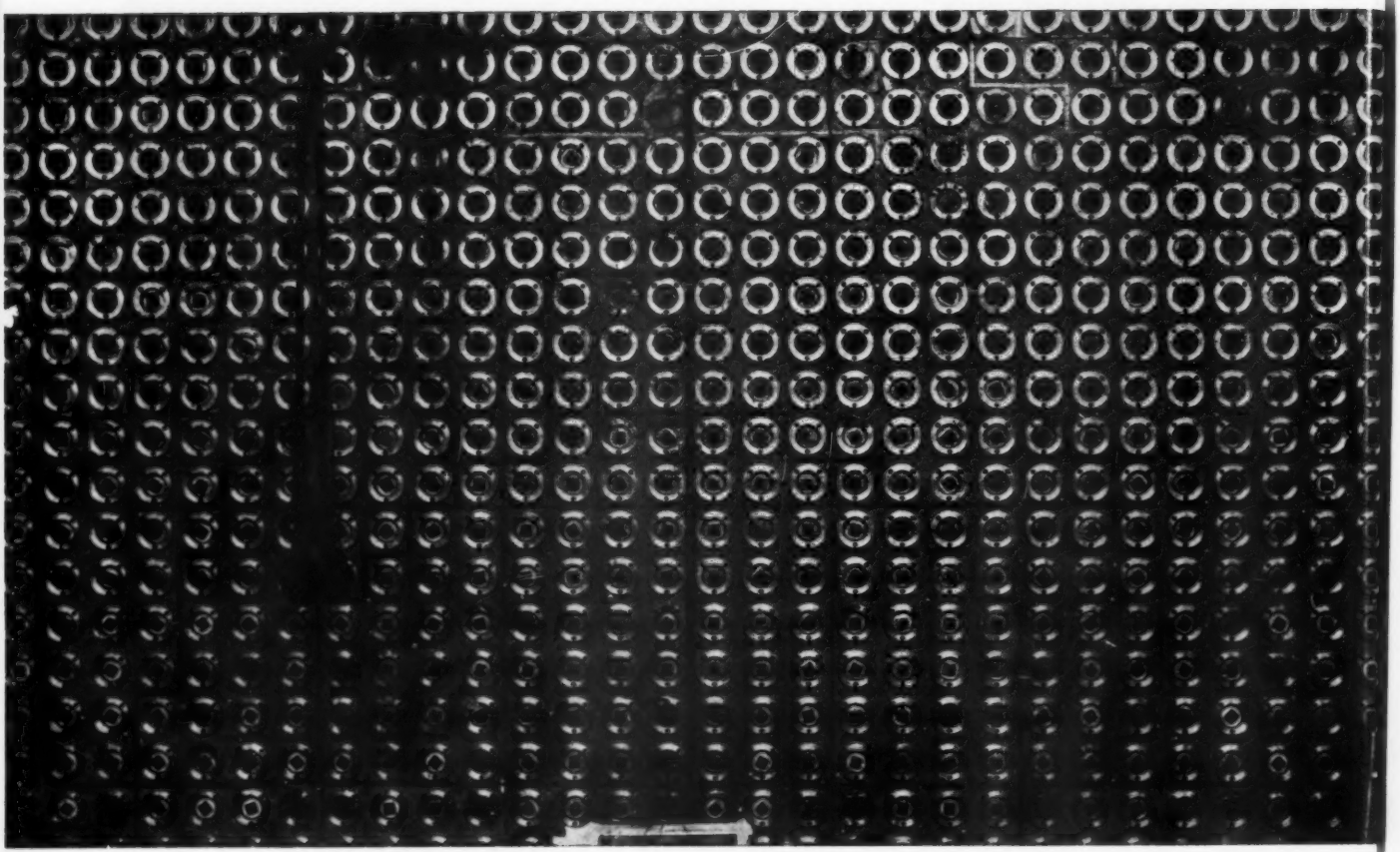

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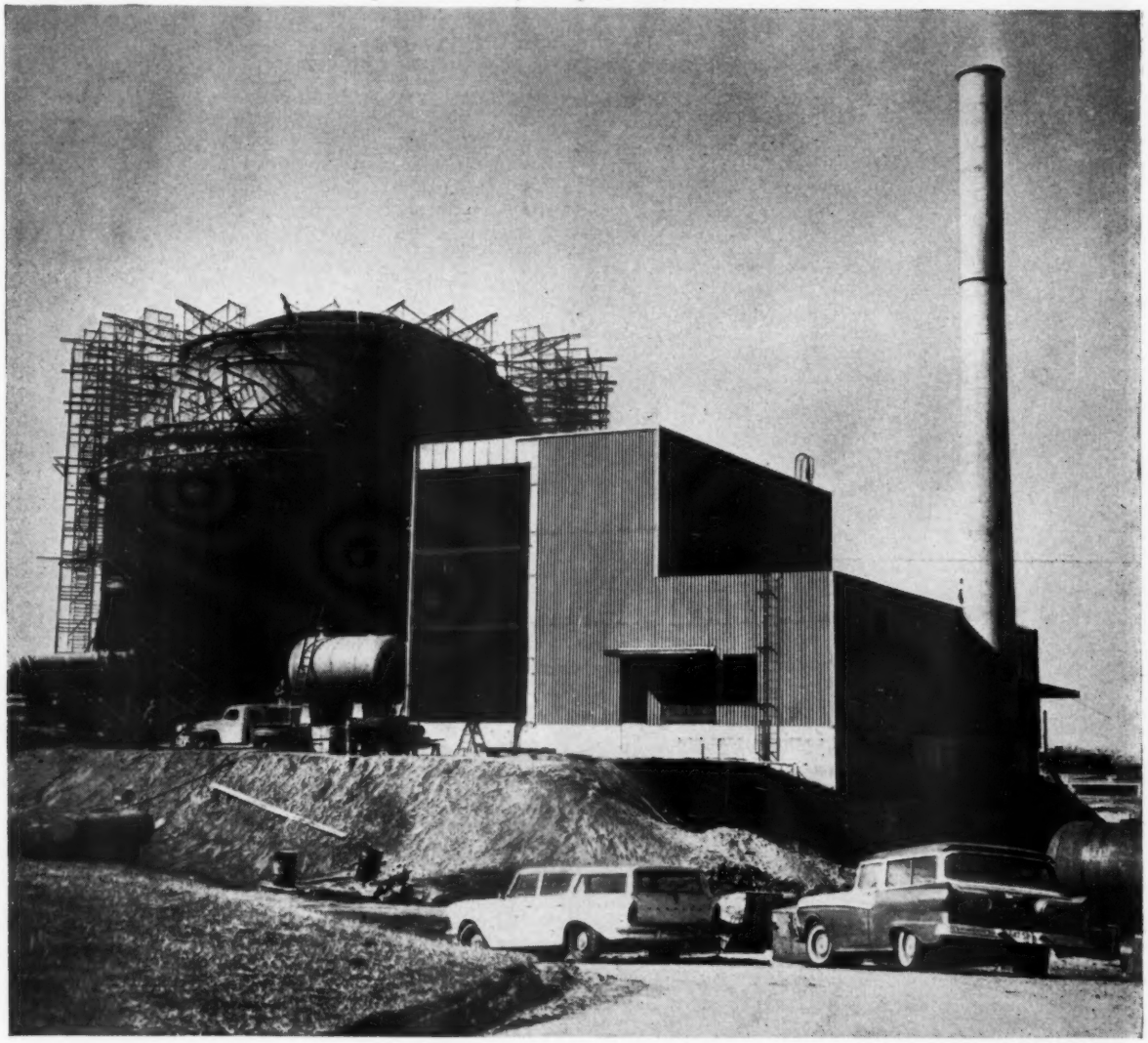

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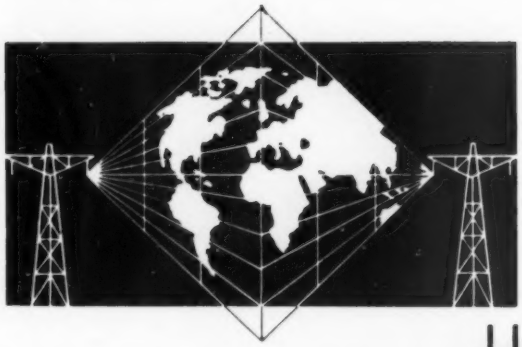

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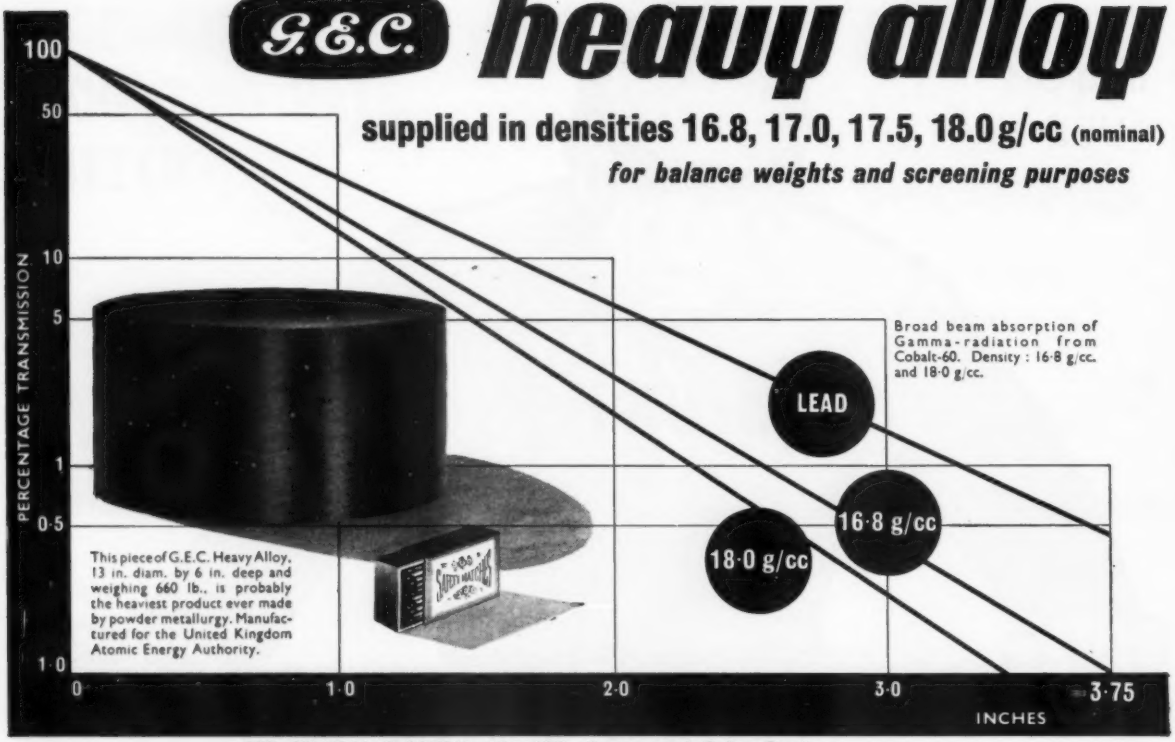

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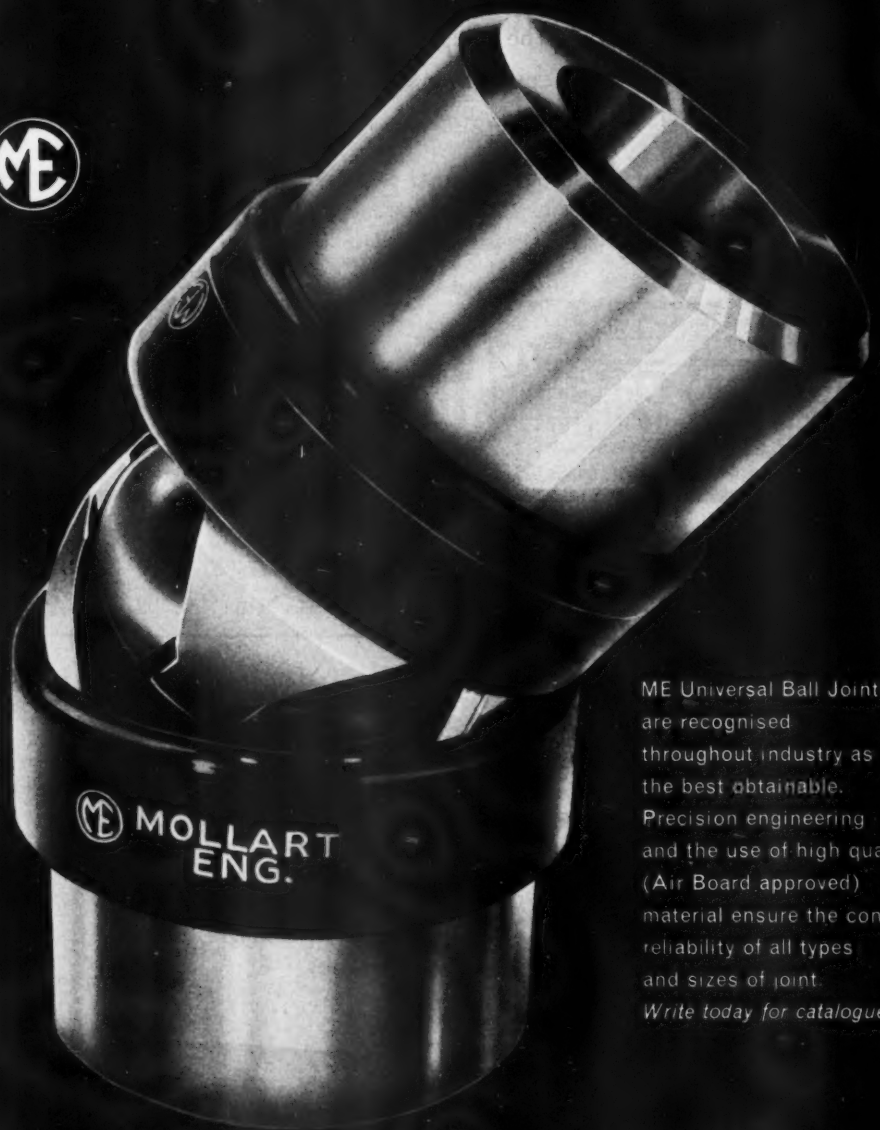

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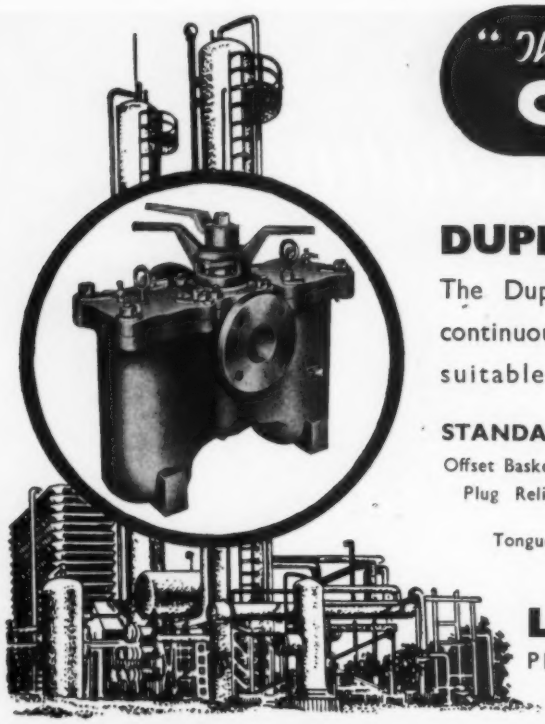

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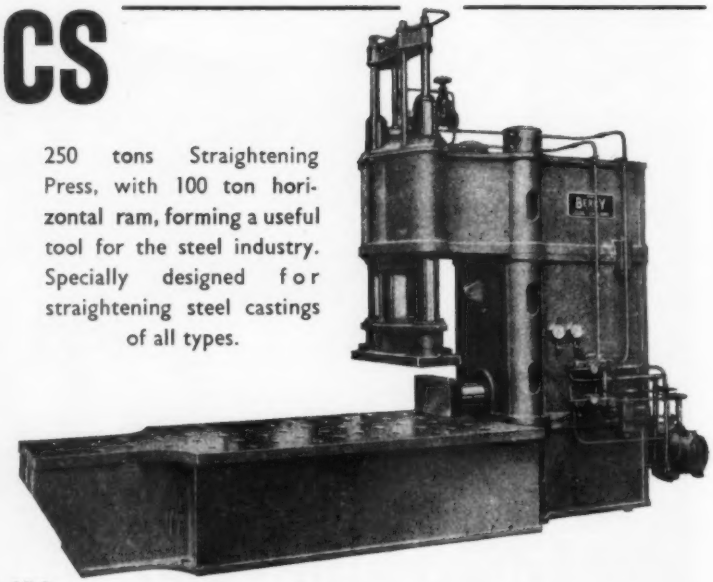

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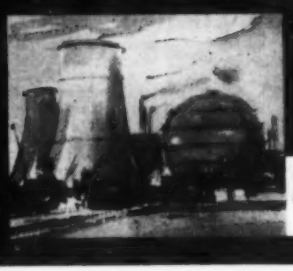

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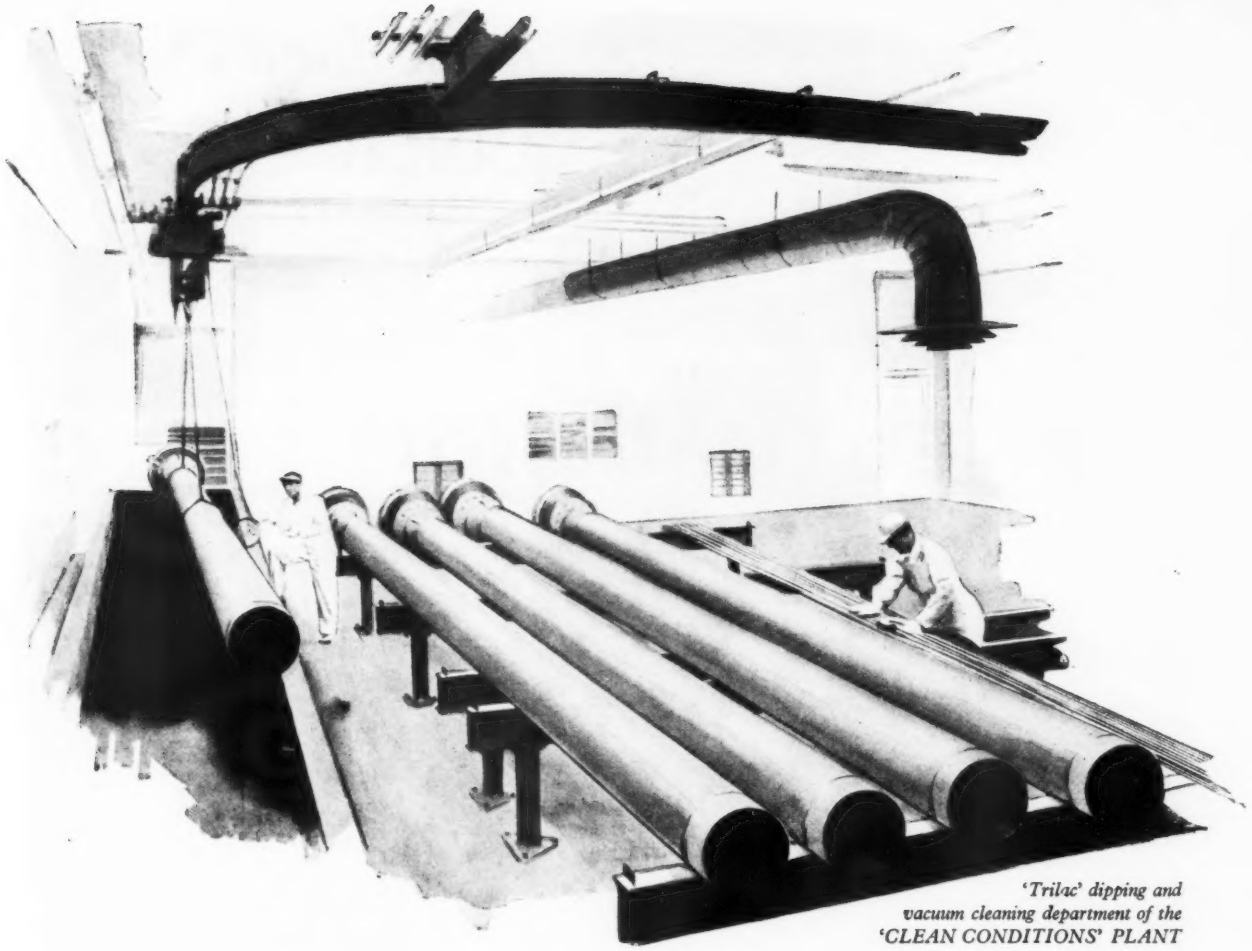

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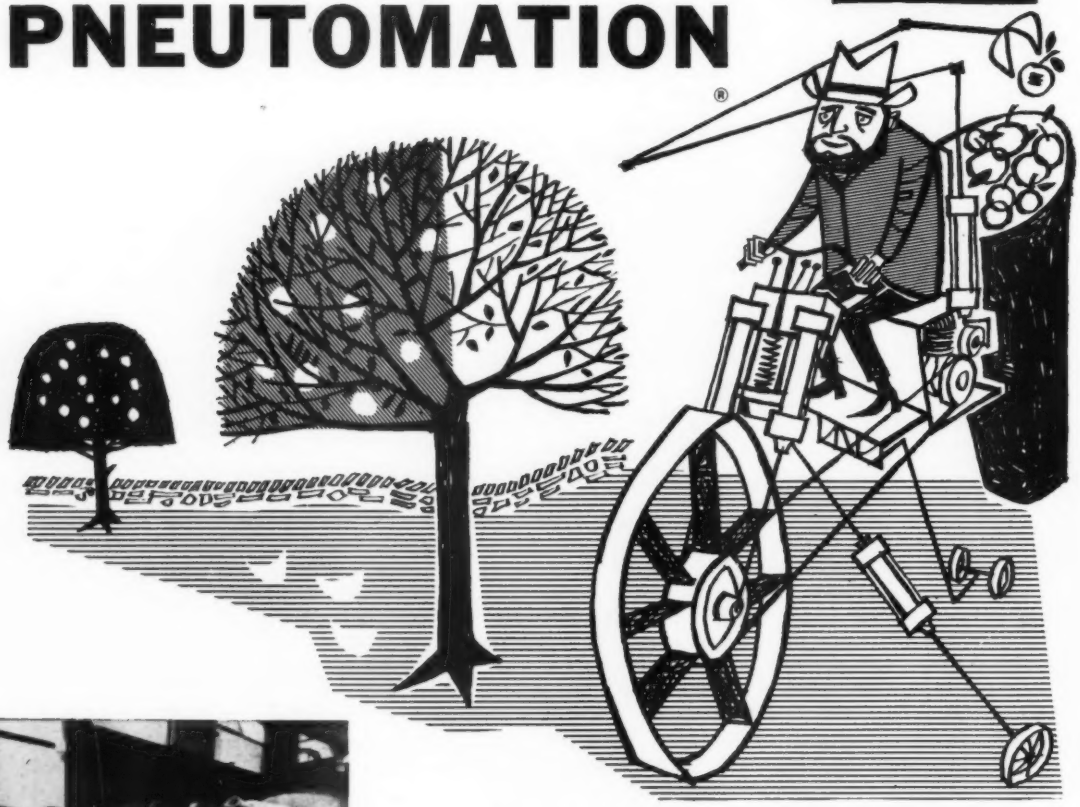

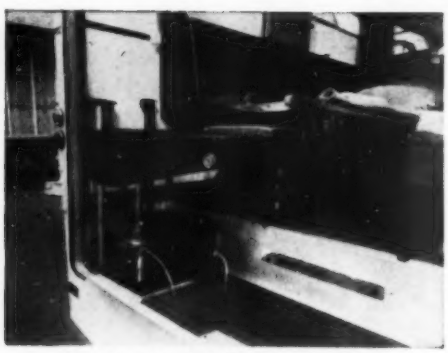

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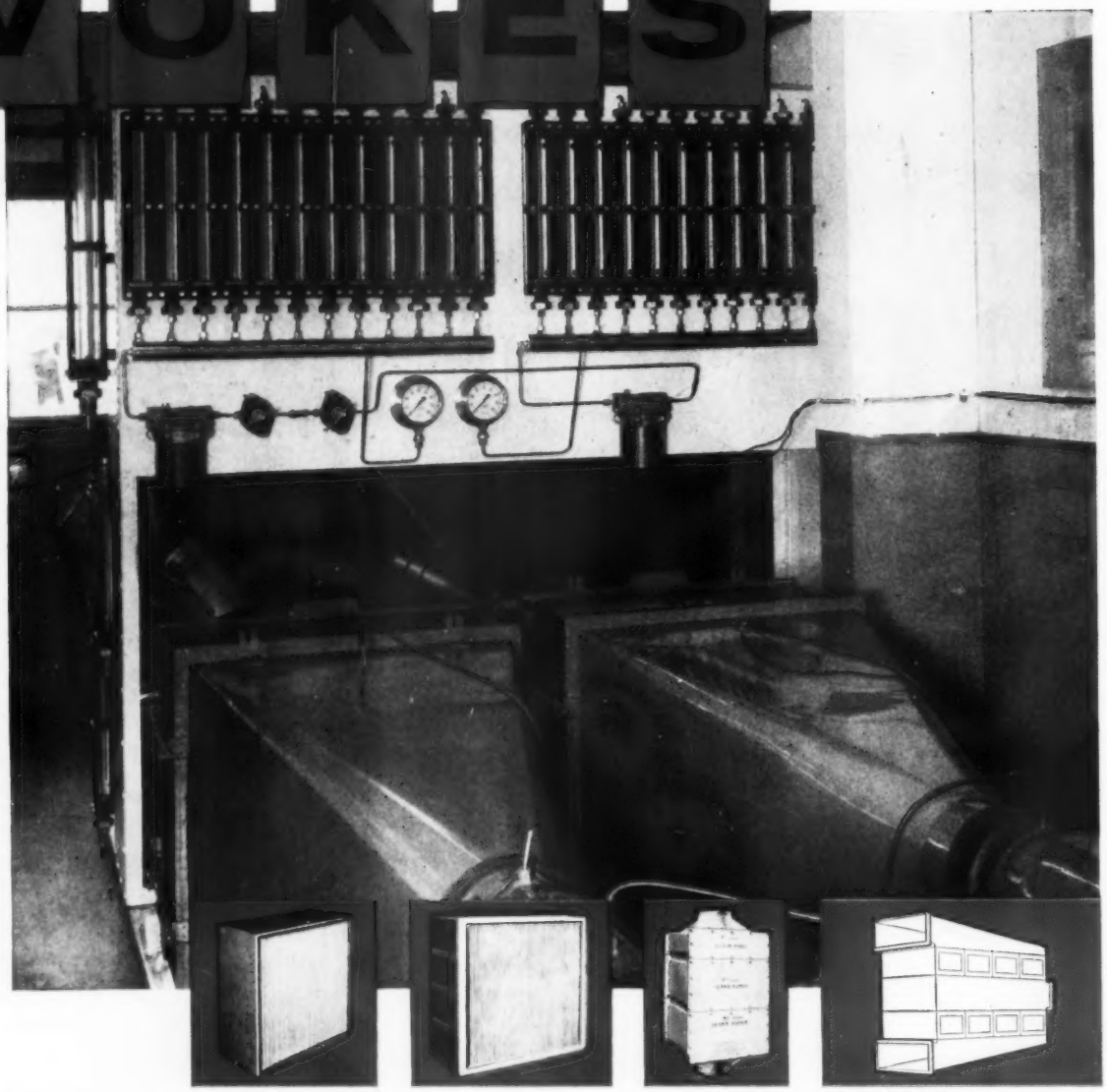

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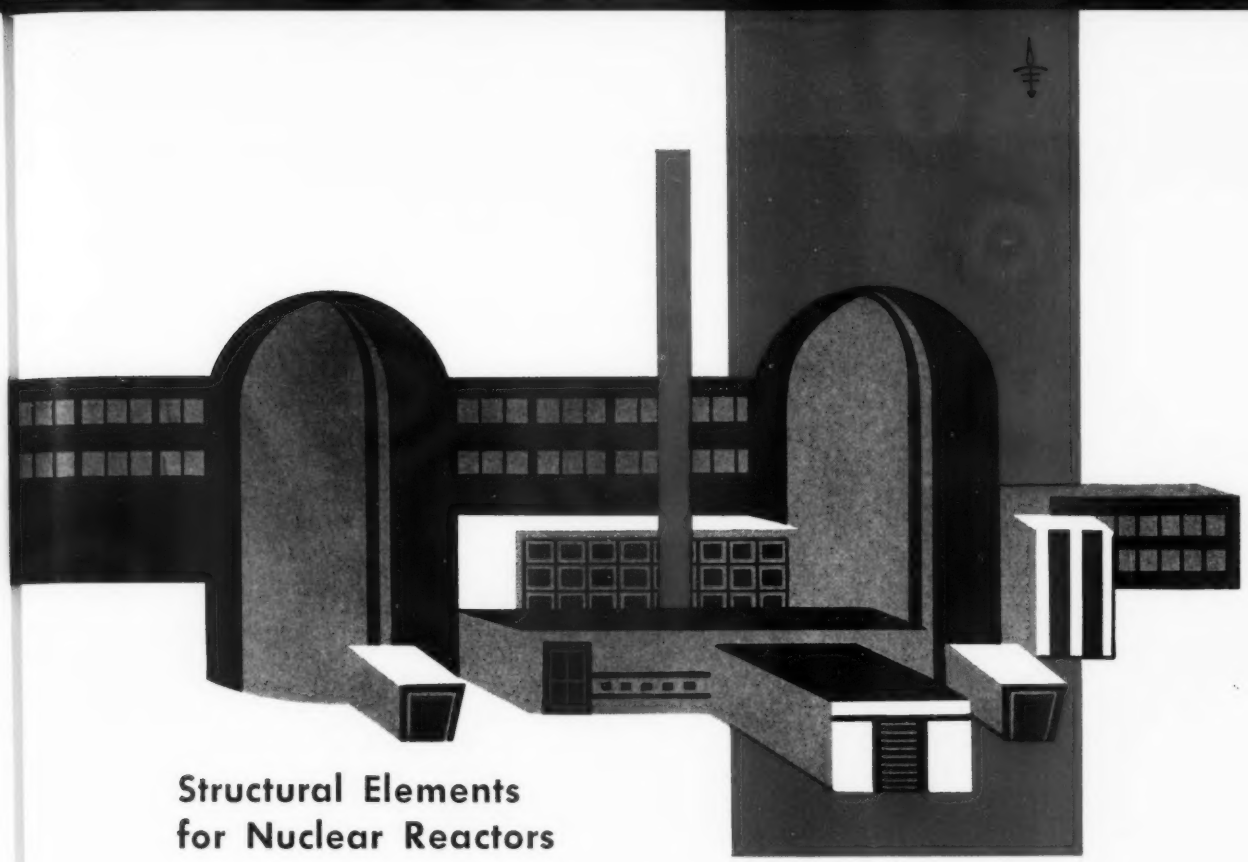

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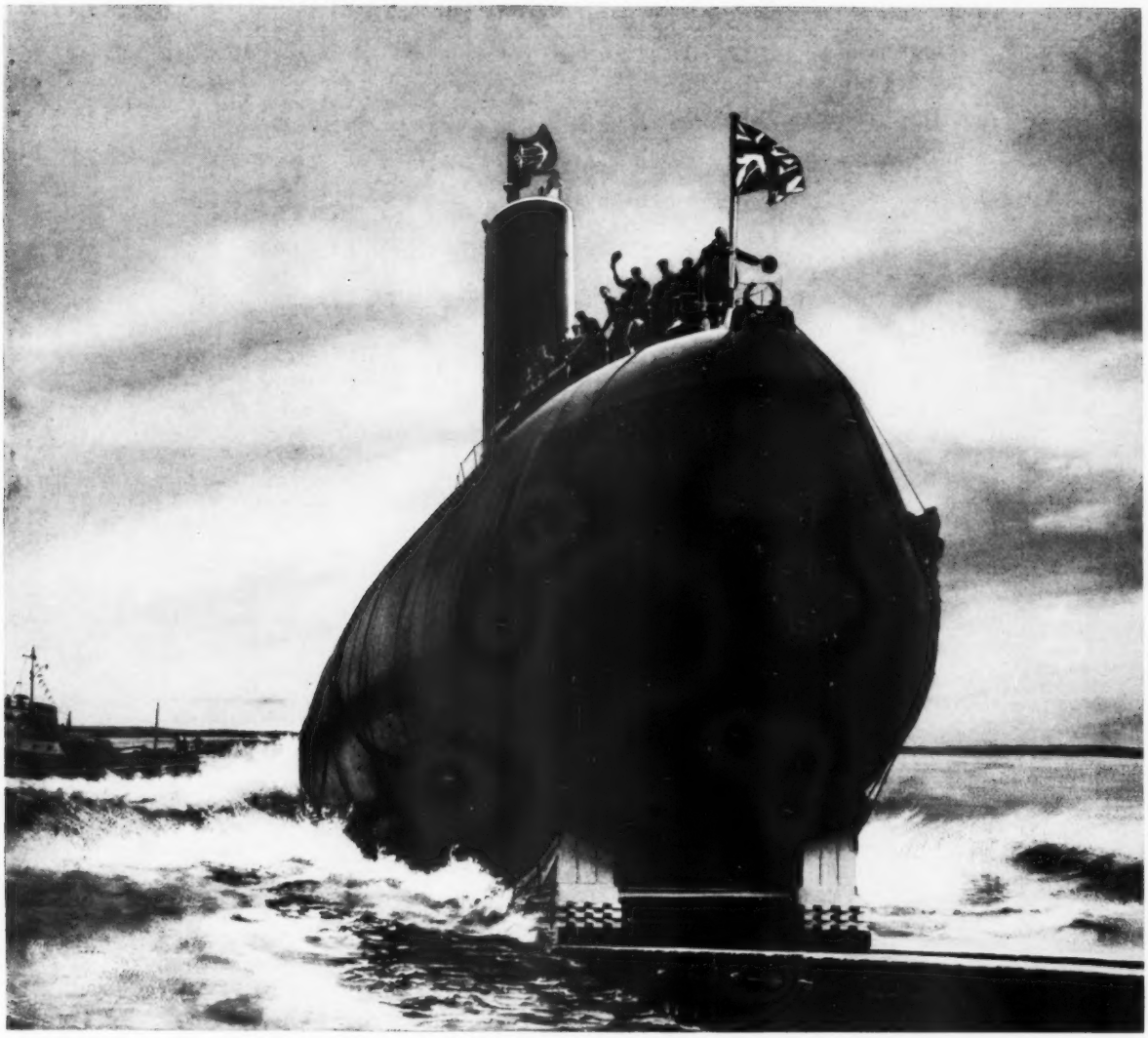

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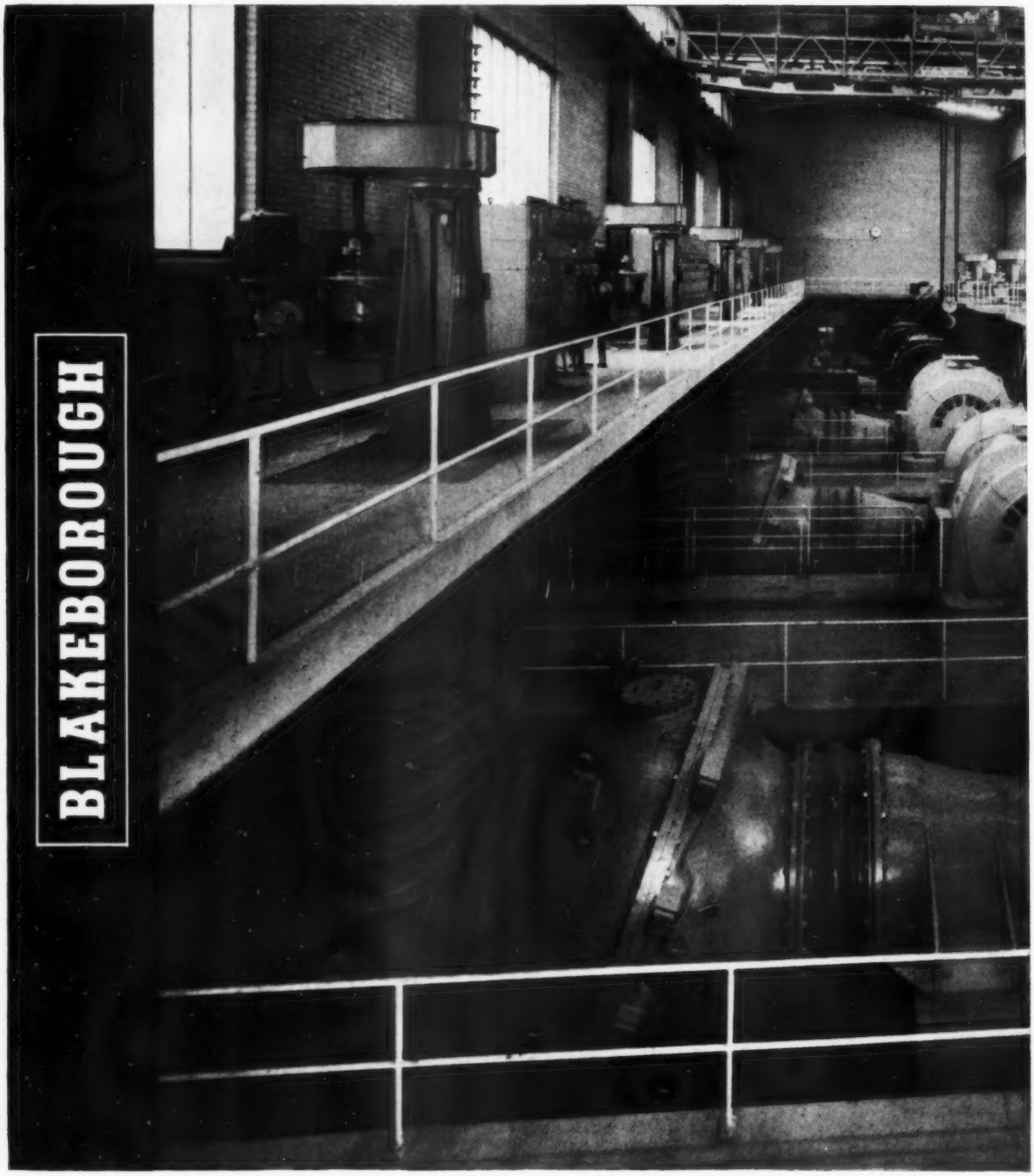

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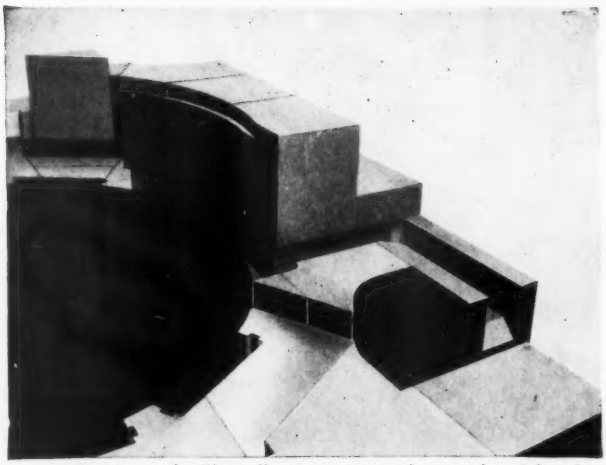

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Nuclear Power AUGUST 1961 VOLUME 6 NUMBER 64

VIEWPOINTS letters to the Editor

US/European Industrial Links

SIR: The article in your June issue entitled 'The US Nuclear Export Drive' contains a table setting out arrangements between American and European Companies. I am concerned particularly about the way in which the Babcock & Wilcox arrangements are represented. In fact, the primary agreement is between the American Company and the British Company, the latter having subsidiary agreements with the German and French Companies enabling them to use American design information.

The arrangement with INDATOM, of which the French B. & W. is a member, was a temporary one in relation to a specific project.

T. B. WEBB
CHIEF ENGINEER AND MANAGER
ATOMIC ENERGY DEPARTMENT
Babcock & Wilcox Ltd
London NW1

Nuclear Ship Design

SIR: Your May leading article entitled 'Nuclear Ship Indecision' discusses concern by the various cognizant authorities over the prospect that the first nuclear ships are uneconomical. There are few people who would disagree with this thought. Having accepted this premise, however, the future course of action appears to be somewhat muddled. Present reactor concepts and present applications of these concepts result in nuclear propelled vessels which are not economically competitive with their conventional counterparts. This may also be said of these nuclear vessels under advanced operating conditions, so-called second and third ships of a design. Why does this condition exist and how can it be overcome?

Most of the design studies conducted to date have had as design objectives minimum ship operating costs and maximum degree of safety; two obviously incompatible objectives. The requirement for maximum safety stems from a desire to obtain public acceptability on an international basis. This desire must be tempered by prudent engineering practice and this has been done to some degree in the designs proposed to date. Full attainment of the appropriate and acceptable degree of safety can, however, only be realized as a result of operating experience with this new plant. We then have the situation where:

(1) We wish to consider construction of a nuclear powered vessel, but it is not economically attractive.
(2) The design is not economically attractive, due in large part to stringent safety requirements.
(3) The safety standards cannot be relaxed because of lack of operating experience which can only be obtained after a plant is constructed and operated.

In view of the preceding, it is necessary to visualize an incentive for construction and operation of these vessels in the future before one starts to accumulate the necessary experience. I feel that no one will disagree that central station power plants will be truly economically competitive in the near future; e.g., the nuclear power programme in the UK. The conditions that make nuclear power attractive there should apply as well to merchant ships with the additional advantage of potential increase in ship carrying capacity due to elimination of fuel oil requirements. The design studies and proposals prepared to date have been based on the approach that one should design a plant based on today's technology with the utmost safety, and, even though it is realized that this ship may not be economically attractive now, show that by some means it will be economically competitive in the future. This is very difficult, if not impossible, since the reference design is inappropriate from an economic consideration. A more logical approach would be that approach wherein one would:

(1) Study the plant concept and application in an effort to determine the minimum requirements of the plant which are necessary for public acceptance from a safety viewpoint and those additional requirements which are necessary for economic competitiveness; e.g., is complete containment necessary; what are the collision protection requirements; what are the standby conventional power requirements; what limits should be placed on the operation of the vessel; limits on activity release; etc
(2) Devise and design an operating prototype for construction whereby one can obtain the experience necessary to justify the required features outlined in the design above.

In other words, attempt to define a marine nuclear plant which would be acceptable without constraint by limitations today, and then perform the necessary developmental engineering toward this end. This may involve modification of present concepts or generation of new ones.

The aforementioned philosophy is implied to some degree by the approach taken by GKSS with the OMR shipboard plant in Germany, by Ansaldo-Fiat in Italy, and by the operation of the *N.S. Savannah* by the United States.

In summary, the problems confronting nuclear ship propulsion today stem primarily from safety rather than purely economic considerations and they can be overcome only by operation of an appropriately defined prototype without which little insight can be gained of the economic potential of this form of propulsion.

R. J. GIMERA
GROUP LEADER
ORGANIC REACTOR ENGINEERING
Atomics International
Canoga Park, California

Burnout heat flux

SIR: Referring to the burnout description in the June issue, it is said on page 63: 'At constant values of the subcooling, and the mass velocity, the "burnout" heat-flux appears to decrease with increasing pressure in the range 500-2000 lbf/in² for water.'

The subcooling cannot be constant when the pressure increases. If the pressure changes, the degree of subcooling also changes ($\Delta T_{sub} = T_{sat} - T_B$). The saturation temperature T_{sat} is a pressure dependent variable and the bulk fluid temperature T_B must be assumed constant.

R. JUNG
Euratom
Weymouth

In the experiments described the bulk fluid temperature is allowed to vary so that the difference $T_{sat} - T_B = T_{sub}$ *remains constant.—Editor*

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OPINION

Is on-load refuelling essential ?

IN THIS ISSUE Mr. Kenneth Dent discusses some of the problems facing the designers of on-load fuel handling machinery. We believe that this is the first authoritative review of the subject. We are now very near the moment when the first machines will be put into operation. It is a good time, therefore to assess realistically the consequences of success or failure of the attempt.

In the first place we should recognise that under the joint vigilance of the licensing Authority, the UKAEA, and the Health and Safety Branch of the CEGB themselves, the machinery at Bradwell and Berkeley will not be used if there is the possibility of any risk to human life. But even if the authorities are satisfied that there is no danger to the operators, there still remains the problem of causing damage to the reactor.

Of all the potential hazards the most serious would seem to be that of the dropped element. A bar of uranium weighing a quarter of a hundredweight and falling sixty feet is a formidable missile. If it lands on a column of highly irradiated elements, softened by high burn-up and at high temperature, what will be the result? Could a pile-up of damaged elements block the channel so that the magnesium overheats and melts? Could the damage to the core be so great as to be irreparable?

Here we have the nub of the problem. If there is a danger of permanent damage to the reactor, then there is no sense in finely calculated plans for fuel cycling designed to lop the odd per cent off the fuel cost. There are two alternatives; either to make certain that it is physically impossible for a mistake leading to serious damage ever to be made while discharging; or else to face up realistically to the alternative, which is to shut down for fuel changing, as the American and Russian systems do.

Would a retreat to fuel handling off load be a disaster? We are not convinced that it would be, for the following reasons:

Availability: The CEGB hope to run their reactors at a load factor of 80 per cent. If they are run at full load or nothing, which is the intention, this availability could be achieved with a shut-down every year for two months (or one month in every six) which would give ample time for fuel changing in complete safety, supposing the right equipment is available.

Reactivity: It is not likely that reactivity would fall away seriously if, say, one third of the core were replaced with fresh fuel annually. If there is a problem, then twice-yearly refuelling could be adopted..

Burn-up: For a given maximum exposure, the mean irradiation of all fuel would be less with bulk reloading. It would be necessary to calculate how serious the effect on fuel costs this would be. Some American fuel cycles (with four of five zones) show a maximum/average ratio or less than 2; this is not much worse than can be achieved by continuous cycling.

Burst Elements: This is the main problem. There are three solutions; one is to tolerate leaking fuel elements and some fission products in the coolant stream, as water-cooled reactors have to do; but this is impracticable in the present generation of gas-cooled reactors. The second alternative is to accept a burst and a forced shut-down (unlikely to be less than 24h.) as a calculated risk. Finally, the existing on-load machinery could be used only for discharging channels developing faults. This would reduce the statistical probability of an accident enormously; operators could take their time and would not be bored by repetition; and it would also reduce wear and contamination of the machinery.

Against this it should be noted that the performance of the fuel elements at Calder Hall has been remarkably good, and in Russia, where effort seems to be concentrated on achieving really good fuel element reliability, rather than fuel handling on load, some very good results have been reported.

We are not posing any easy answer to this problem; we recognise that on-load fuel changing is a most desirable aim. We suggest, however, that just because this aim was set six years ago and everyone has accepted it ever since as one of the design criteria, there is nevertheless no cosmic law which says that it is an easy or even a feasible thing to do. It would not be a disaster for gas-cooled reactors if on-load fuel handling were not carried out; but we would like to know whether the alternatives have been prepared for. The change in operating procedure of the existing reactors would be great; the change in design of future reactors would be fundamental.

Another question that should be asked is whether the perfectly natural secrecy of charge machine designers about their own companies' designs is not holding up development unecessarily. With important problems still to be solved, perhaps greater collaboration now would be worthwhile in the long run.

Finally, there is the part we hope the gas-cooled reactor will play in the export industry of this country. Those destined for operation in less-developed countries require to be as simple as possible, as there will be few highly skilled operators available. Reactor designs have tended to become more complex rather than less over the last few years, and there is an urgent need to reverse this trend by some hard questioning of all the original assumptions. Sir Christopher Hinton's remark at the opening of Calder Hall remains as true today as it was then: it is more important to be successful than to be clever.

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WORLDVIEW

the month in atomic energy

EUROPE

AEA to drop AGR beryllium plans?

London After several years work, the UKAEA is to drop its plans to build a beryllium fuel-canned advanced gas-cooled reactor in the near future. *Nuclear Power* understands. Research and development has been cut and a recently completed design study for a commercial AGR is based on the use of stainless steel as the fuel canning material.

The AEA's annual report states that tests on the corrosion of beryllium in carbon dioxide have shown that under the higher temperature conditions in the AGR, more corrosion can take place than can be tolerated in an AGR. Until the condition under which beryllium stands up to AGR environment is clearly understood and can be specified, it has been decided to delay the introduction of beryllium-canned fuel elements into the Windscale AGR. (The proportion of beryllium-canned elements to be used has fallen from 80% to 20% and these will initially be loaded into the cooler parts of the reactor.)

Because of this, *Nuclear Power* understands that the Authority has now decided that on technical and economic grounds, beryllium is not an immediate possibility for use in a commercial nuclear power station.

Against this, reports from Australia tell of continued interest and work on beryllium. They say that corrosion in carbon dioxide is markedly accelerated by the presence of water vapour but that purification can bring the amount of water vapour down to acceptable limits. They also state that controlled amounts of oxide in the metal increase the corrosion resistance. Opposed to this, however, is the problem of ductility at high temperatures and low strain rates. This is aggravated by the presence of oxide.

Carbon dioxide to be dropped?

Another change that is being discussed is that of using helium in an AGR for cooling instead of carbon dioxide. Certain sections of the Authority are said to be very interested in the possibility of using helium which, though more expensive, would considerably reduce corrosion problems. It seems that provided full advantage is taken in designing for stainless steel canning and helium cooling the reactor would be very much sounder as a technical proposition without there being too severe an effect on its economics.

BR-2 goes critical The 50 MWt *BR*-2 high flux materials testing reactor went critical at Mol on July 1. Designed by the Nuclear Development Corporation of America, the reactor will have a thermal flux of 10^{15} n/cm²/sec. Construction started in September 1957.

Reactor for Ispra The Dutch Neeratom group is to design a 1 kW heavy water-moderated reactor for the Euratom research centre at Ispra, Italy.

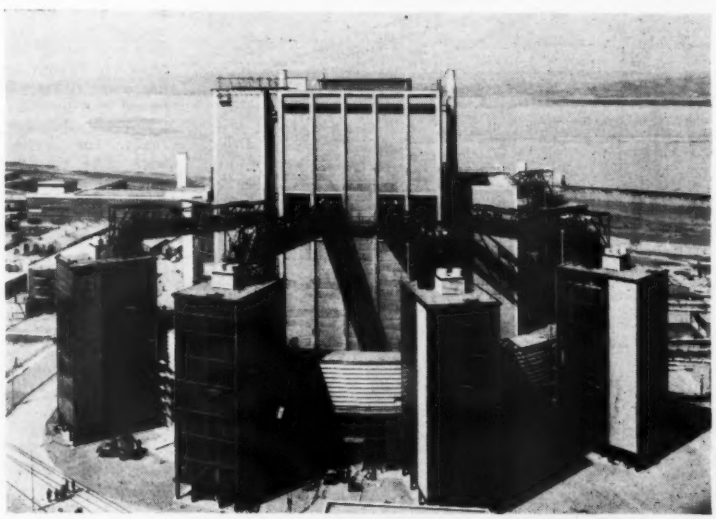
EDF-1 fuel loading Mechanical loading of fuel into EDF-1, the 63 MW, natural uranium, graphite moderated gas-cooled reactor at Chinon, France, has started.

CEGB pay £300,000 for Oldbury tenders

London Following protracted negotiations (see *Worldview*, December 1960, p 73) the UK Central Electricity Generating Board has finally decided to pay for nuclear power station tenders. The amount decided on is £100,000 which will be given to both successful and unsuccessful tenderers. *Nuclear Power* understands that this arrangement will apply only so long as CEGB continues to order nuclear power stations on a turnkey basis.

It has been difficult to arrive at a definite figure. The amount must not be so high that a consortium could make a profit by re-tendering an old design modified to suit the site in question, nor so low that the losses sustained by the unsuccessful tenderers become unbearable.

The new system has been put into immediate effect with payment for Oldbury for which tenders are due in on August 14. No compensation will be offered in respect of past tenders.



BERKELEY READY. The No. 1 reactor at Berkeley nears completion. Criticality is expected to be reached soon (See page 54)

WORLDVIEW

French oppose Euratom reactor subsidy

Brussels French opposition to Euratom financing of power reactors was openly admitted after the Council of Ministers approved a first allocation of $19 million towards this aim. (See *Worldview*, June, p. 53.)

The voting, by a qualified majority, in favour of Euratom's participation, was five against one by France. After the meeting early in July, M. Etienne Hirsch, a Frenchman himself and also Euratom's president, admitted there had been a difference of opinion. It is understood that the French Minister of State for Scientific Research, M. Pierre Guillaumat, had received official instructions to oppose any action by Euratom outside the field of basic research. The reasons he gave were that the 'subsidy' for power reactors would be an unnecessary expense and would impair other research programmes.

For Euratom, M. Hirsch defended the view that there should be a good balance between funds for pure research and practical development. The credits voted—a total of $32 million out of the $125 million research fund raised by members for the five year period ending December 31, 1962—represented only 15% of the total under the five year plan.

The money is to be spent on three reactor projects: Latina, SENN and SENA. French objections were also on the ground that the aid would be going mostly to British and American designed projects. However, Italian influence and support for the scheme is believed to have tipped the scales against France. This latest disagreement also spotlights reported differences between Euratom and France over the rôle of Marcoule and the transfer of information from this centre to Euratom under the provisions of the Rome treaty. The French, it is said, cannot yet decide whether Marcoule's operations are military or civil though money for the centre is provided under the civil budget.

Insurance scheme Another scheme where French plans were not entirely accepted was when Euratom discussed methods for sharing out financial charges coming from the payment of damages under an insurance scheme against nuclear risks concluded by member states.

The French plan was that these damages should be calculated on the basis of each country's national product. The Germans, however, said it should be based on the power developed by each country's nuclear installations.

A compromise was reached and the Council of Ministers stated that for a period of ten years, the sharing of charges would be based 50% on national product and 50% on maximum thermal power developed by nuclear installations.

Under the Euratom insurance scheme, member states are collectively responsible where damage is between $70 million and $120 million.

TRAWSFYNYDD BOILERS. So far at Trawsfynydd nuclear power station one boiler has been lifted, another has been stress relieved and hydraulically tested and is ready for fitting with tube element supports. A third was being lifted (above) at the time of the recent press visit before being placed in the stress relieving furnace. All the works end of boiler manufacture is expected to be finished by the end of the year which will be ahead of schedule (see p. 80 for details of site workshop etc)

Berkeley/Bradwell ready for fuel loading

London Both the Berkeley and Bradwell nuclear power stations are expected to go critical shortly. Fuel loading will begin as soon as authority is received from the Ministry of Power. *Nuclear Power* understands that either one of them could receive this permission first or possibly simultaneously.

Once loading starts, criticality is reached within two to three weeks; this will be followed by a period of testing and low power operation. Assuming both these stations start fuel loading within the next four weeks, they should be supplying their rated output to the national grid by February or March next year.

The AEA, Mr Micawber and a nuclear ship

London The failure so far by the Ministry of Transport to make a decision on a nuclear powered ship was criticised in a recent House of Commons debate on shipping. It elicited the reply from Mr Marples, the Minister of Transport, that he hoped—but could not promise—to make a statement before Parliament rose for the summer recess.

Opening the debate, Mr F. T. Willey said he gathered from the AEA's annual report, wrapped up in some Micawber phraseology, that the experiment in nuclear propulsion had been a failure. Who, he asked, was going to be sacked for this? We had reached the stage where we were staggering from disaster to disaster and from failure to failure because we were ruled by faceless men with anonymous responsibility.

Replying, Mr Marples said we had to spend our limited resources in the most advantageous manner and we had to decide what is best. He would rather make a decision which was right and slightly late than one which was wrong and made too quickly.

AMF reactor for Britain?

London Talks have been held between Pye Ltd, Cambridge, and a number of interested companies on the possibility of setting up an industrial research centre grouped round an AMF reactor. Discussions are continuing.

It is believed that the centre, if built, would be similar to the Industrial Research Laboratory facility in Plainsboro', New Jersey. This has an AMF research reactor and is owned by a consortium of ten companies, including AMF.

Pye is the licensee for AMF reactors in the UK and is at present making a strong bid to supply research reactors to British universities.

New 50 MW research reactor for Karlsruhe

Bonn A new multi-purpose research reactor is to be built at the Karlsruhe research centre. Named the MZFR (Mehr-Zweck Forschungs Reactor), it will be fuelled by natural uranium and cooled and moderated by heavy water. Capacity of the reactor is given as 200 MWt with a production of 50 MWe. The facility will be capable of testing fuel elements, radiation of reactor materials and producing radio-isotopes.

According to Dr S. Balke, the West German Minister for Atomic Affairs, who made the announcement, the government would contribute 100 million marks towards the cost and the electricity supply companies, 30 million marks for the electricity-producing equipment. Building will take three years and will be carried out by Siemens-Schuckertwerke.

Dutch look into BWR possibility

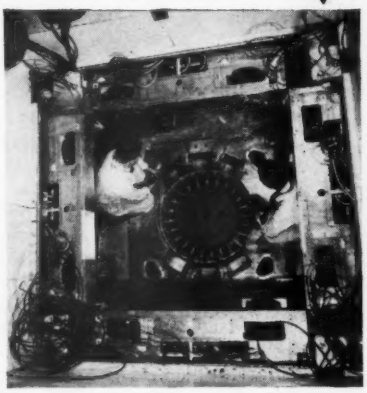
New York The award of a contract to carry out a joint study on a 50 MW boiling water reactor with a group of electrical concerns in the Netherlands has been announced by the US General Electric.

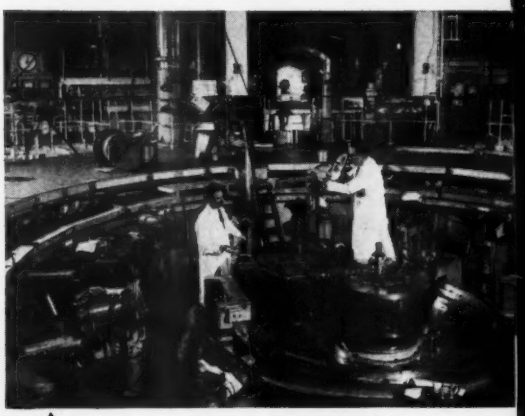
The contract is with the SEP group of Arnhem (Samenwerkende Electriciteits-Productievedrijven) and the study will cover preliminary design of a BWR which SEP is considering for possible construction in the Netherlands.

The study is expected to provide a design concept for a plant that will produce power at reasonable cost; provide engineering information during operations which would be useful in the design of larger stations and provide physics data which would aid in the development of future nuclear plants.

AEA REACTOR PROJECTS

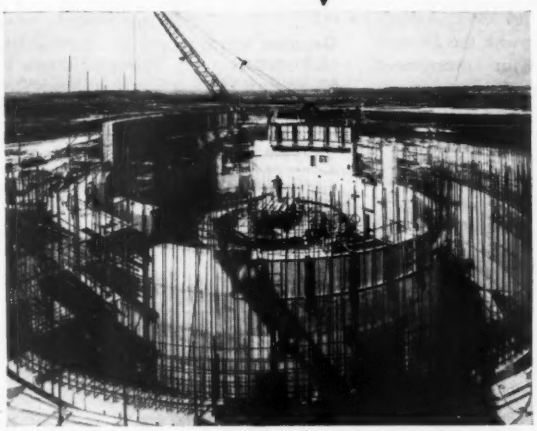
The core of the NESTOR reactor at Winfrith under construction. The reactor went into operation recently ▼

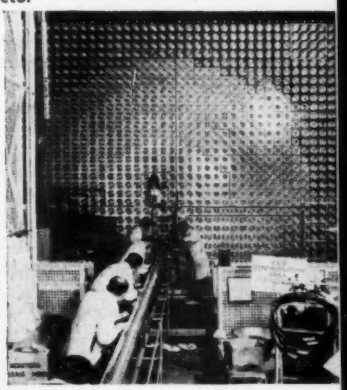




▲ An introscope mounted over a charging hole through the inner rotating shield of the Dounreay Reactor

The building to house the OEEC DRAGON High Temperature Reactor project at the AEE, Winfrith ▼





▲ A large thermally insulated tube being loaded into BEPO at Harwell

Study starts on Berlin power reactor

Berlin Three companies—two US and one German—have been engaged by the electric utility serving West Berlin to conduct a closed-cycle water reactor study for a 151MW nuclear power plant for that city.

The study will serve as the basis for a proposal to build the plant under the joint US-Euratom power reactor programme. It will be undertaken for Berliner Kraft und Licht (BEWAG) AG by Westinghouse Electric Corporation, Kaiser Engineers and Constructors Inc. and Siemens-Schuckertwerke AG. The work could be realised by 1955-66 and meet the deadline for completion of projects under Euratom's 'second round' programme.

Westinghouse and Kaiser will co-operate in studying the nuclear steam generator. Siemens will undertake the design and engineering of the conventional equipment and take part in the overall planning of the project.

The way things are developing, it appears that this station will be competing with three others for consideration under the Euratom 'two reactor' second round programme. Other likely applicants are the Franco-Belgian SENA group, Germany's KBWP (formerly the AKS) group and SEP (Samenwerkende Electricteits Productiebedrijven) which recently contracted with the US General Electric for a design study of a 50MW boiling water prototype plant.

University reactors delay There has been another delay on the part of the British Government in the allocating of money for university reactors. The House of Commons was told discussions were still proceeding. It is now expected no decision will be made until after measures to combat the present economic crisis are announced.

Soviet physicists in the UK A party of six Russian scientists, headed by Mr V. E. Ivanov of the Physico-Technical Institute of Ukranian Academy of Sciences, is in the UK on a ten-day visit. The first three days were devoted to an informal symposium at Harwell and then visits and further discussions on Solid State Physics Research.

French training reactor A 'training' reactor designed primarily for student training at universities has been completed at the French Saclay centre. The enriched uranium, light-water cooled facility, ULYSSE, has an output of 100 kW. It may be the prototype of a model for commercial sale abroad, the CEA states.

WORLDVIEW

Euratom moves on marine propulsion

Brussels While Britain is playing the tortoise over marine propulsion, Euratom is haring ahead with more investment in marine propulsion research and development projects. As expected, the six nation Commission has signed agreements to take part in the following three projects:

1. The Italian Fiat/Ansaldo project for a complete draft design for a nuclear-powered tanker. Euratom's investment will be around $1·2 million over the two-year programme.

2. The Netherlands Reactor Centre's (RCN) three year programme for adapting a PWR-type reactor to marine propulsion requirements with the ultimate aim of preparing a complete PWR marine design. Euratom is prepared to contribute $1·9 million.

3. The GKSS (Hamburg) project, to which Euratom is to invest about $1·8 million, for a number of shielding and vibration tests covering five years.

This extension of the Commission's marine activities, starting with the January 27 contract with GKSS for development on an OMR type reactor, means that its plans also cover the PWR and possibly the BWR in addition to a general research programme. At the same time, Euratom is to arrange for a comprehensive technical and economic study to be carried out by a group of leading shipping experts on such questions as tonnage, type of transport, length of voyages etc, for which nuclear powered ships will be most suited in the future.

Decision expected on German power reactor

Duesseldorf Germany's largest electric utility company, RWE, (Rheinisch Westfalisches Electrizitatswerke) is examining tenders for a 250-300 MW nuclear power station. A decision is shortly to be made, according to German reports and should it be decided to build the station, it will be set up at Bertoldsheim, near Neunurg an der Donau. Building will probably start in 1962.

RWE operates the 15 MW Kahl BWR and (see *Nuclear Power*, March 1961, chart, p 80) has had before it proposals by the GEC/MAN and English Electric/Deutsche Babcock und Wilcox for magnox stations.

German working group Representatives of 25 enterprises in Schleswig-Holstein have set up a working group to study uses and applications of nuclear energy in industry and transport.

Kahl power upgrading The nuclear power station at Kahl (BWR), whose output is now at 3 MW, is to operate at 15 MW in the near future.

Ionising Radiations statute Revisions in the requirements for the protection of workers against ionising radiations are laid down in a new statutory draft of the regulations published by the Ministry of Labour. They take the place of the regulations published on April 29. The draft is substantially the same as the original and in the main, merely clarifies meanings.

Bashful Swedes AB Atomenergi scientists are reported working on project BASHFUL (Boiling and Super-Heating Heavy Water Full Scale Study), a design study of a 400 MW direct cycle D_2O BWR with natural circulation and internal superheating. The study will be completed early next year.

Norwegian nuclear ship Norway will build a nuclear powered merchant ship within the next five years if talks to be held by the European Nuclear Energy Agency in Paris in September are successful, according to Mr. S. Randers, director of the Atomic Energy Institute, Kjeller.

AEA's fuel sales rise

London During 1961-62, the Atomic Energy Authority expects to receive about £13 million from fuel element sales, the House of Commons was told recently. Mr Denzil Freeth, Parliamentary Secretary to the Minister for Science, said the Authority received £2 million from sales in 1960-61 in addition to £6.5 million advance payments received in 1959-60.

On the Dounreay Fast Reactor, Mr Freeth said the number of professional staff employed had approximately doubled since last year. It was not, however, currently planned to run the DFR completely on plutonium fuel.

OVERSEAS

GE to build competitive BWR

New York A competitive 325 MW (gross) boiling water reactor is to be built by the Pacific Gas and Electric Company at Bodega Bay, 50 miles north of San Francisco. The president of PG&E, Mr N. R. Sutherland, says that the plant will produce electricity, based on a 90% load factor, at 5·62 mills per kWh on its first core and 5·32 mills on the second. Costs from a comparable conventional plant using oil and in the same area, would be about 5·78 mills.

The reactor will be supplied by the US General Electric Company and contract negotiations are still underway. It will be a forced circulation BWR with internal steam separation, giving a net output of 310 MWe. Saturated steam will be produced at 554°F at a pressure of 1000 lbs per square inch. Thermal efficiency will be 32-33%.

An underground concrete and steel structure, 125 ft in diameter and 100 ft deep will enclose the reactor. Containment will be of the pressure supression type. The core will be some 75 tons of 2·5% enriched uranium pellets encased in stainless steel rods. Estimated life of the core is 3½ years.

Capital cost of the project is $61 million including $2 million for transformers and switching equipment. Installed cost per kilowatt will be about $181. An additional $8·5 million will be required for fabrication of the first core and $2·25 million for transmission lines. Construction will start in August 1962 and full power operation in December 1965. No contribution is being sought from the AEC for research and development, PG&E state, and the company will pay the full fuel charge established by the AEC.

The company and the GE are at present engaged in building a 60 MW BWR at Humboldt Bay which is expected to be completed next year.

Process heat reactor Four paper and pulp firms are interested in taking part in an AEC demonstration low temperature process steam project incorporating a nuclear reactor. An invitation for detailed proposals is likely to be issued soon.

Undersea portable reactor General Dynamics Corporation is developing a portable, self-regulating nuclear power plant to generate electricity beneath the sea or in remote land areas. The reactor of up to 2000 kWe capacity will have fuel elements similar to those used in *TRIGA* research reactors.

Fuel cell submarines The US Navy is working on fuel cell-powered submarines, according to Admiral J. T. Hayward, Deputy Chief of Naval Operations for Development.

Antarctic Plant bids

Washington Invitations to submit proposals for a 1MW portable nuclear power plant for the Antarctic have been invited from US industry by the Atomic Energy Commission. The invitation covers research and development and the design and building of a plant which should be capable of producing 1·5 million Btu's per hour of steam. Shipment of the plant is to be scheduled for late 1963. It will be designed to facilitate re-location during its 20 year anticipated life.

Soviet thermonuclear aims Professor V. Yemelyanov, chairman of the USSR Atomic Energy Committee, said in Poland that he thought 'our generation and perhaps, I myself, will see the opening of the first thermonuclear power station.'

Moroccan reactor? A reactor may be used to provide steam for a new phosphate rock drying process under study on behalf of the Moroccan Government by Dorr-Oliver Incorporated, Connecticut, USA. A decision may be reached at the end of this year.

More Soviet ships Russia is to build more nuclear powered ships according to a report from the Russian news agency, TASS.

USSR/Japanese agreement? The Soviet delegate at the IAEA proposed that the USSR and Japan conclude an atomic energy agreement, Mr M. Ikeda, chairman of the Japanese AEC, said on his return from a tour of Europe and the US.

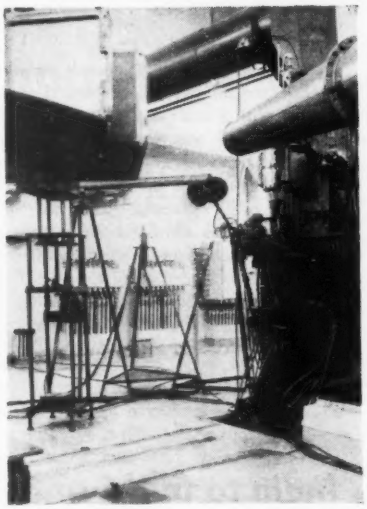
Canadian-UK uranium Representatives of the UKAEA have visited uranium mining companies to discuss costs, according to Canadian reports. These visits relate to the UK-Canadian talks on the British 'commitment' to buy 12,000 tons of uranium which were held recently but have been adjourned.

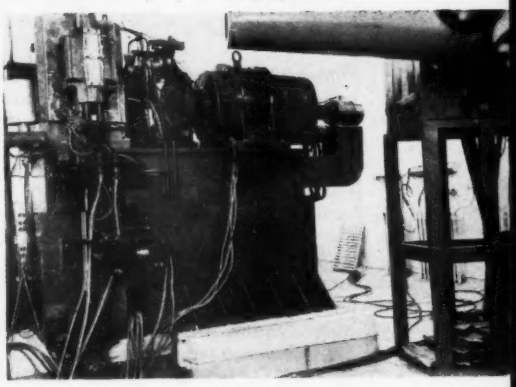
Soviet reactor nears completion The reactor forming part of the Latvian research centre at Salaspils is nearing completion, according to the Soviet Economic Gazette. The 2000 kW facility is to go critical in October.

US help for Pakistan reactor Pakistan officials are reported to have had talks with AEC officials on the possibility of US help for Pakistan nuclear power stations.

Yankee costs less Final costs of the 110 MW Yankee nuclear power station at Rowe, Mass., were expected to be $13 million below estimates, it was disclosed recently.

Critical assembly General Electric Japan Ltd is to supply a light water critical assembly to the Japan Atomic Energy Research Institute.





RUSSIAN PULSE REACTOR. First pictures of the Soviet fast neutron pulse reactor which recently went into operation at the Joint Nuclear Research centre, Dubna, near Moscow

AEC issues SL-1 accident report

Idaho Falls Idaho A report presenting findings on the SL-1 (Stationary Low Power Reactor No. 1) accident which occurred on January 3 has been issued by the US Atomic Energy Commission. This supplements an initial report made on January 27 (See *Nuclear Power*, March, p 96).

The report says that at the time of writing (May, 1961), there still remains substantial doubt concerning the initiating event causing the explosion within the reactor pressure vessel. It summarizes current information before the Board of Investigation and states: 'Prior to the accident, there appear to have been a continuing deterioration of the burnable poison strips within the core and a worsening of the scram performance of the control rod system, neither of which circumstances necessarily was directly related to the incident.'

'The evidence strongly indicates a nuclear incident of 50 megawatt-seconds, or more, which could credibly have been induced by rapid and extensive motion of the central control rod. There is no evidence to show that the actions of the operators on duty were in any way different from those prescribed and which had been carried out without incident many times before.'

Shortly before this report was issued, an advisory committee of reactor experts appointed to explore the future use and disposition of the SL-1, filed a second interim report. This definitely established that the reactor vessel was dry and that the core had been distorted and substantially damaged.

The committee proposed that shielding be placed on top of the reactor to permit assessment of the contamination in the reactor building. This would seal off radiation from the reactor core and the resulting reduction in the radiation level outside the reactor vessel would give a measure of the contamination in the building.

A copy of the complete accident report, including annexes, charts and photographs, is available for examination at the offices of Nuclear Power, *77-79 Charlotte Street, London, W1. A limited number of copies are available from the AEC's Office of Public Information, Washington 25, DC.*

The new US U-235 charges

The following examples of the new base charges for enriched and depleted uranium in the form of uranium hexafluoride have been provided by the AEC. The changes took effect on July 1, 1961 (see *Worldview*, July, p 57).

U-235 ASSAY (WEIGHT %)	NEW CHARGES		PREVIOUS CHARGES	
	$ PER KG CONTAINED U	$ PER GRAM CONTAINED U-235	$ PER GRAM CONTAINED U-235	PER CENT REDUCTION
ENRICHED URANIUM				
90	12,285·00	13·65	17·07	20
20	2547·00	12·74	16·12	21
10	1195·50	11·95	15·29	22
5	535·50	10·71	13·96	23
3	281·20	9·37	12·52	25
2	160·00	8·00	11·00	27
1·5	102·60	6·84	9·70	29
1·0	49·90	4·99	7·58	34
DEPLETED URANIUM				
0·7	22·60	3·23	5·45	41
0·6	14·80	2·47	4·48	45
0·5	8·05	1·61	3·33	51
0·4	3·00	0·75	2·04	63

If a user specifies a U-235 assay between 0·4 and 0·22 weight per cent, the charge will be $3 per kilogramme of contained uranium. However, if the U-235 assay is not specified by the user, the AEC will supply uranium having a U-235 assay to be determined by the AEC in the range below 0·4% and will charge $2·50 per kilogramme of uranium.

WORLDVIEW

Canada's NPD delayed six months

Ottawa Manufacturing difficulties with the calandria for the 20MW Nuclear Power Demonstration plant (NPD) contributed towards a delay in completing the station, says the annual report issued by Atomic Energy of Canada Ltd. The reactor is some six months behind schedule and is now expected to go critical by the end of the year and reach full power early in 1962.

On the Douglas Point (CANDU) 200MW project, the report says the estimate of total costs remains unchanged. Design and development of this project is well under way and construction at the site has reached the stage of pouring the concrete foundations for the reactor building. The station is to be in full operation in 1965.

Turning to OCDRE, the organic cooled D_2O moderated reactor, the report states that a decision on whether to go ahead with an experimental plant is expected soon.

The annual report followed another released by a special research committee of the Canadian House of Commons which generally approved of AECL actions so far. This conclusion was reached after committee hearings at which criticism of the AECL and the CANDU reactor were expressed, notably by Winnett Boyd, president of Arthur D. Little Ltd of Canada. Mr Boyd stated that CANDU would not operate on natural uranium alone and that some 10% of the price of the initial fuel charge would be taken up by enriched uranium. He also pointed out that with the present reactor development programme, Canada would eventually have to build heavy water plants; this would go against studies which showed that building uranium enrichment plants was preferable. He proposed that work on NPD be accelerated so that the feasibility of CANDU could be ascertained as quickly as possible.

For the AECL, the president, Mr J. Lorne Gray said he expected the third CANDU reactor would be directly competitive with 5 mill power. He also pointed out that AECL was working on a proposal to '*foster some incentive for burning Canadian uranium in a Canadian type reactor*'. This proposal was not quite ready for publication. Earlier, before the Canadian Nuclear Association's conference, Mr Gray indicated that for CANDU a burn-up of at least 9750 MW/d per metric ton could be achieved and heavy water losses could be kept at an acceptable rate.

Savannah ready for sea trials

Washington Tests are scheduled in the immediate future for the *N.S. Savannah*, the American nuclear-powered merchant ship. According to the AEC programme, these tests will take place in late July or early August and will be followed by sea trials.

The *Savannah* is at present at the New York shipbuilding yards, Camden, New Jersey, where she was built at a cost of $35 million. Hearings on the ship's safety have been completed and no reason has been found to delay completion.

After fuel loading and operation at zero power, the vessel will be moved to Yorktown, Virginia, where full power testing of the 60 MWt PWR will be carried out followed by sea trials.

SNAP crackles aloft A SNAP (Systems for Nuclear Auxiliary Power) isotopic-fuel thermoelectric generator is powering two transmitters in the US satellite 'Transit-4A'. (See *Isotope Review* this issue).

Plastic reactor critical Initial criticality has been reached in the Batelle Plastic Reactor Facility which is to be used in an energy conversion study. The reactor operates at power levels up to 200 watts to provide neutrons to the direct conversion cells placed in the centre of the reactor.

Brazilian reactor plans Brazil intends to have two reactors in operation by 1966, Professor M. Damy de Souza Santos, director of the Brazilian Institute of Atomic Energy said in Paris recently. He was speaking after the signing of a mutual aid agreement on nuclear research between France and Brazil.

India to build small nuclear station

Bombay India is shortly to decide whether to build a 20 MW nuclear power station. A formal announcement is expected soon, according to the annual report of the Indian Department of Atomic Energy, as detailed cost estimates have already been prepared. The reactor will be fuelled by natural uranium, moderated by heavy water and organically cooled. Other studies underway include fast reactors, pressurized water reactors and heavy water moderated reactors.

The report only mentions in passing discussions with the USSR. No information, for instance, is given about the possibility of the Russians supplying a power reactor. However, on the Tarapur 300 MW station for which tenders are due by August 31, 1961, the report says selection of the successful tenderer would be completed by the end of 1961 and work should start immediately after. Present plans envisage the first of the station's two reactors being commissioned four years after the start of work and the second six months later. On the project for a 150 MW station for the Delhi-Punjab-Rajasthan area, the report says no decision has yet been made on a site.

Production facilities A larger uranium metal processing plant for an extension to the present facility is being considered. Cost estimates and preliminary process designs have been completed. Expansion is also being considered for the fuel element fabrication pilot facility whose present production is about 3-40 tonnes per year.

Construction has started on a used fuel reprocessing plant (Project Phoenix) to handle irradiated fuel from the 40 MWt CIR reactor. It is to be completed by 1963.

The heavy water plant, with an annual productive capacity of 14 tonnes, is expected to go into production towards the end of 1961. All the equipment is being supplied through Linde AG of West Germany.

Research Experiments on various lattice arrangements of beryllium oxide and uranium ore are being carried out by the Tata Institute of Fundamental Research under an agreement with the French Atomic Energy Commission.

Under an IAEA contract, work is being carried out to develop a method of non-destructive analysis of irradiated fuel for U-235 and its plutonium content by measuring the fission rate and different neutron energies.

Congress cuts plan for Hanford Conversion

Washington Plans to convert the $145 million plutonium production reactor at Hanford, Washington State, to produce between 650-760 MWe received a setback when the House of Representatives rejected the project. By a vote of 176 to 140, the House denied the Kennedy Administration's request for $95 million to carry out the conversion. Apart from this, the AEC appropriations bill for $258,440,000 for 1962 was passed.

The case against conversion was largely based on the issue of public *v.* private power (see *Gracchus*, this issue) and also on objections that the project would not advance nuclear power technology. According to American sources, however, there is a possibility that the US Senate may restore the cut when the bill comes before them.

AEC amends licence The USAEC is to amend the University of Illinois' reactor operating licence to allow the performance of TRIGA reactor pulsing experiments.

Mock Up reactor The US National Aeronautics and Space Administration is to build a low power pool type reactor (Mock Up Reactor) to investigate reactivity effects and other nuclear properties of experiments before they are inserted into the Plum Brook reactor.

Seventh AEA Annual Report

WITH ITS theme once again 'steady progress,' the AEA's 1960-61 report was received without much incident at the annual press conference where the report was discussed. In a muted atmosphere, Sir Roger Makins, the AEA chairman, made the following points: Calder Hall had completed five years of successful operation; the first fuel charges for Bradwell and Berkeley were being loaded; the AGR was almost up to programme though three months were lost by unofficial strikes; the Dounreay Fast Reactor entrainment problem had been solved and operations would soon be restarted; reorganization of the AEA had been carried out smoothly and net expenditure had fallen by £15 million because of increased receipts.

As a bonus, Sir Roger looked into the immediate future and announced that a team of Soviet physicists would be coming to the UK this month (July) under the recently-signed Soviet-UK agreement.

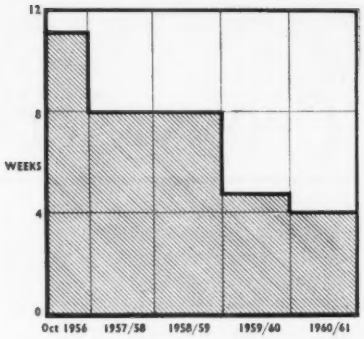
As a result of the questioning that followed, the AEA disclosed that 45% of its research effort was devoted to the development of new reactors; that a 'lot of studies' were being carried out on heavy and light water moderated reactors as they showed promise in smaller sized reactors though no further steps had yet been taken; that the Central Electricity Generating Board had sufficient information to build a commercial AGR (presumably with stainless steel canned fuel elements as beryllium corrosion problems have not yet been solved); that future tenders for civil power stations would include concrete pressure vessels and that studies to find out whether magnox cans would crack under the thermal cycling programme in civil stations would be finished in three months' time.

Disappointingly, for three years have passed since the first news was released, the Steam Generating Heavy Water Reactor concept is still being studied. The best the AEA could say was that a detailed design study had been completed and a joint development programme was underway with Canada.

Reactors

The eight Calder and Chapelcross reactors, the report says, gave almost trouble-free operation throughout the year. In one irradiation experiment in a Calder reactor, a number of fuel elements reached 2250 MWd(H)/t and some individual fuel elements had exceeded 3000 MWd(H)/t by early 1961. However, the Authority says that while it has no reason to doubt the assumption that for civil power stations average irradiation would be 3000 MWd(H)/t, sufficient time had not yet elapsed to test the civil reactor fuel elements to this irradiation.

On the Steam Generating Heavy Water reactor, an assessment was completed on the basis of a detailed design study and the Authority is engaged on solving some of the key problems of which some apply to other heavy water moderated reactors. Because of this, a joint development programme is to be carried out with Atomic Energy of Canada Ltd. No decision to build a reactor experiment had been taken though the design of one exponential and one sub-critical assembly started in January 1961 as part of the development programme.



Average time taken to complete the scheduled refuelling and maintenance of Calder and Chapelcross reactors

Arrangements have been made to supply fuel materials for future submarine reactor cores, including that for the second nuclear submarine. Further work on reactors for merchant ships is to be concentrated on more advanced systems such as the high temperature gas-cooled system.

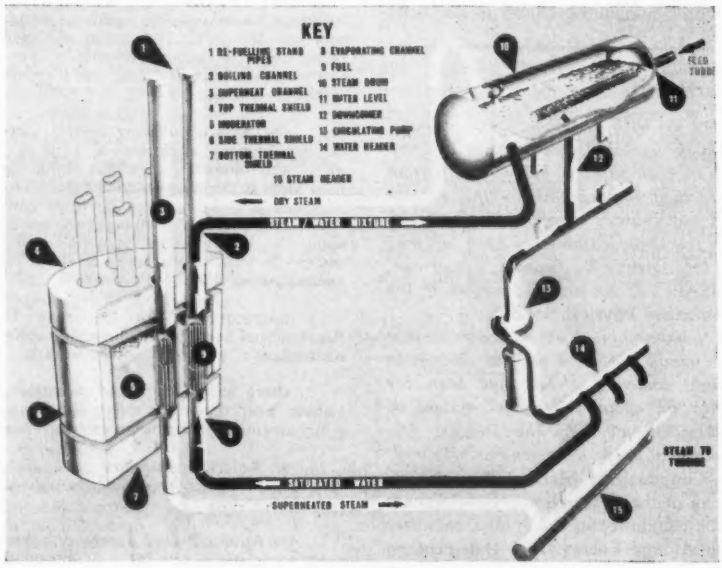
Fuel elements

The out-of-pile testing of pre-production models of civil fuel elements continued. Certain weaknesses of design which allowed the fuel elements to move in the gas stream have been eliminated. Measurements of the gas forces which cause some deformation of the fins and splitter plates have been made. Other tests indicate that with severe thermal cycling, magnox cans will crack and work is in hand to establish the likely degree of thermal cycling in the civil stations and its effect on the life of the fuel.

Tests on the corrosion of beryllium in carbon dioxide have shown that under the higher AGR temperatures, more corrosion can take place than can be tolerated in an AGR. Until the results of further investigation, the AGR charge will be mainly stainless steel-clad elements. It is thought that a satisfactory solution to the detailed design of the fuel element cluster which must allow for expansion of the individual fuel rods and yet ensure that they cannot vibrate has been found. A large endurance loop to test civil AGR elements under appropriate conditions is being designed.

Gas centrifuge

It has become 'necessary to review the centrifuge to see what effects the new technologies might have on the centrifuge as a means of separating isotopes and to examine their bearing on the technical aspects of disarmament.' A small development programme has been started.



The Steam Generating Heavy Water Reactor

Cross Section by GRACCHUS

ONE OF THE PERVERSE results of Hawker Siddeley's decision to close its Langley plant has been an increase in work for its JASON reactor. This has risen to a point where apart from being used for giving instructions to parties from APC and elsewhere and for flux experiments for the AEA, the research establishments at Harwell, Winfrith and Risley have been keeping the JASON team busy. In addition, the Royal Naval College, Greenwich, are showing interest in JASON though with certain modifications which HSNP are trying to convince them to do without. Interest, too, is being shown by AEI, though there is no official confirmation of this. But it is known that leading AEI executives from Aldermaston have visited Langley and that discussions have reached the stage of 'hard cash talks.' AEI's interest in this is said to be as a sales prospect. One partial result, also caused by the complications of closing the plant down, is that key men are staying on by request—strengthened by a considerable monetary incentive.

AN INTERESTING SPECULATION has arisen about fuel charge machinery for a concrete pressure vessel reactor. Half of this 400 ton machine is shielding and adds considerably to the difficulties of positioning and movement. If, for instance, the pressure vessel walls were carried on upwards so that the charge machine itself could be enclosed in a pressurized area, and remotely-controlled, of course, there would be no need for shielding and the machine would be easier to manipulate. I believe this is shortly to come out of the 'speculation stage.'

AT THE SAME TIME as the USAEC announced its downward price changes in its base and lease charges for enriched uranium, it also said, discounting the official verbiage, that it was thinking of allowing private ownership of 'special nuclear material.' This could mean 'free market' purchases of uranium concentrates which could be enriched in AEC diffusion plants on a toll charge basis. I also gather that the real significance of the price changes has been greeted with some caution. My rough estimate that the cost effect on current designs will be some 3% of total reactor costs appears to be in line with US estimates of 2 to 5%. One point that was made here was that adjustments will have to be made to fuel reprocessing costs which may well reduce some of the benefits of the reduction.

BRITISH ENGINEERS are having an interesting but arduous time dealing with some of the problem of using concrete pressure vessels for nuclear power stations. Answers have been found for most of these but I understand that two problems—cooling the steel liner and placing the boilers—are still proving difficult. It water is used for cooling, corrosion problems become severe. On the other hand, as the French have found, carbon dioxide cooling is difficult to design for and may lead to hot spots due to temperature variations. The problem with the boilers is to make the most of the new concept. The obvious way is to put them inside the vessel but heavy shielding from the core is then necessary, again because of corrosion problems.

THE VOTE AGAINST THE KENNEDY Administration's proposal to convert the Hanford plutonium producer to electricity production (see Worldview this issue) has apparently revived the previously dormant debate over public v. private power in the US—a controversy which had its heyday during the Roosevelt Aministration and the setting-up of the Tennessee Valley Authority. I understand that prior to the debate, pressure groups representing the private utilities and the coal industry and unions 'lobbied' successfully against the project. Indeed, a Democratic senator, Henry M. Jackson of Washington is reported as saying that the vote was a victory for the private utility industry and the coal industry—the losers being the American people. However, more serious points put against the conversion were that it would not advance nuclear reactor technology and that conversion would lead to subsidized power being used to attract industry away from other regions to the Pacific northwest. These arguments seem strange to English ears. One would hardly have expected such peculiarly-based opposition to electricity being produced from Calder and Chapelcross.

On record

'I do wish to emphasize . . . that I believe materials research, in addition to its basic interest, has very important practical implications to the welfare of our country. Support for this work in the United States has been lagging.'

Dr Glenn T. Seaborg, chairman, USAEC, at the annual banquet of the American Physical Society.

'I have pointed out many times that we could have had nuclear aircraft in flight today if it had not been for the "on again, off again" system of mismanagement by the Defense Department and its scientific advisers.'

Congressman Melvin Price, Chairman of the Research and Development Sub-committee of the Joint Committee on Atomic Energy, in a statement on the cutbacks in the US aircraft nuclear propulsion project.

I hear that . . .

. . . **Egypt is interested** in 'buying' a hot laboratory from the UK and that preliminary details have been discussed with a firm of consulting engineers.

. . . **the first Euratom-Canadian-US** meeting on co-operation over heavy water reactor technology took place at Ispra recently.

. . . **the Atomic Energy Authority** has given up its effort to impose a solid fuel element on the Tokai-Mura reactor. However, this idea was pursued quite strenuously for a time.

. . . **present thinking** about a commercial fast breeder involves passing the coolant up through the core and not down and that the number of coolant loops could come down to as low as four.

. . . **MAN of Germany** has now completed its design for an AGR ship reactor in conjunction with the GEC. The design will shortly be put up to the Federal Government in order to attempt to secure financial—and if possible, Euratom—backing.

. . . **the AEA is suffering** from a surplus of development engineers—a surprise to many who thought the surplus would have been more in the pure research field.

. . . **the CEGB is thinking** very seriously about a high-powered materials testing reactor to back up its facilities at Berkeley nuclear laboratories.

. . . **operators on the Dounreay** Fast Reactor head have to wear breathing apparatus because of a mercury vapour hazard.

. . . **there has been heated** discussion in Canada over the lower safety factor apparently accepted for the CANDU pressure vessel.

. . . **an American Standard** UTR reactor may well be chosen by a Scottish university for research work.

. . . **the Atomic Energy Authority** is getting ready to release a new batch of information which will enable practically any organization to design a gas-cooled magnox reactor.

Research into the behaviour of reactor materials will be the principal target of the new CEGB laboratories.

RESEARCH AT BERKELEY

by J. SPENCER BURKETT, Assistant Editor, 'Nuclear Power'.

THREE MAIN LABORATORY groups form the heart of the Generating Board's research and development organization. The Leatherhead laboratories, whose work has been mainly in the fields of generation, transmission and distribution, are now extending their interests into high voltage and materials research. The recently established Central Engineering Laboratories are also looking into generation and transmission, but the projects to be undertaken will be large scale and of an advanced nature. The third group, centred on the new establishment at Berkeley, is exclusively concerned with problems arising from the operation of the civil nuclear power stations. Its programme of work is directed towards improving the efficiency and reliability of nuclear power generation leading to a reduction of costs, and the maintenance of high safety standards.

The Berkeley laboratories will look at uranium, canning materials, magnesium and magnesium alloys, zirconium and zirconium alloys, graphite, and pressure vessel steels. Specimens for this research will come from facilities installed in the CEGB reactors, and from other sources. They will try to understand the fuel element through all the stages of its life, e.g. how uranium bar behaves, what is the cause of deformation, at what ranges the bar bows. They will investigate the relationship between can failure release of fission products and the behaviour of the bar and how far it is influenced by the canning material.

This kind of examination is carried out at Calder Hall and Windscale but research at Berkeley will be rather more detailed. Investigations will be made into can failure, the rate of deformation, the prevention of fuel elements entering the beta phase, etc. Existing knowledge of fuel element failure gained from Calder Hall operation cannot be used to prejudge what will happen in the CEGB reactors, as operating temperatures will be rather higher. There is not a great deal of experience in the higher temperature range of the combined effect of cans and fuels. The loading of fuel elements after the first charge is put in, with the reactor running at pressure, may present other problems; thermal shock, for instance, is an important feature. Another topic of significance is the complicated phenomenon of uranium growth for which no real theoretical basis has yet been established. There are numerous theories about many of the mechanical and physical effects that occur in reactor components, but there is a need to gain much more experimental data. Practical investigations are needed into cavitation, the direction of can straining, fin deformation, and notch effect, canning thickness and load bearing characteristics.

For research into all these many problems, the Berkeley laboratories are suitably equipped both in staff and equipment. Basic work will proceed alongside the study of materials from reactors. Similar materials handled under different conditions will be compared, the aim being not to divorce fundamental research from applied.

RESEARCH FACILITIES

Shielded Area (180 ft × 100 ft) storage pond, 3 caves, 9 cells, lead box suites

Engineering Hall (160 ft × 115 ft × 60 ft high) Rigs: atmospheric heat transfer, pressurized CO_2 heat transfer, fuel element endurance tests, vertical channel visual flow; fuel element thermal cycling, fuel element end closure deformation, fuel element specimen preparation and test facility; reciprocating seal tests, reactor pressure circuit tests

Laboratory Wing
Laboratories for: analytical chemistry, general metallurgy, hazard chemistry, solid state physics, health physics and nuclear instrumentation, graphite, electron microscopy, physical chemistry, X-ray diffraction, metallography, spectrometry.

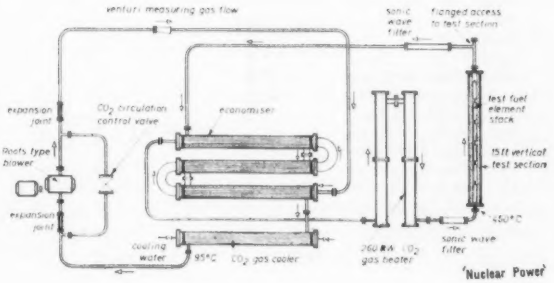
The new £2 million Nuclear Research Laboratories, built beside the Severn, are close to No. 1 reactor of the Berkeley Nuclear Power Station. No. 2 reactor is off the picture to the right (Fig. 1)

Main buildings: 1 Laboratory Wing—physics and metallurgy 2 Shielded Area 3 Engineering Hall

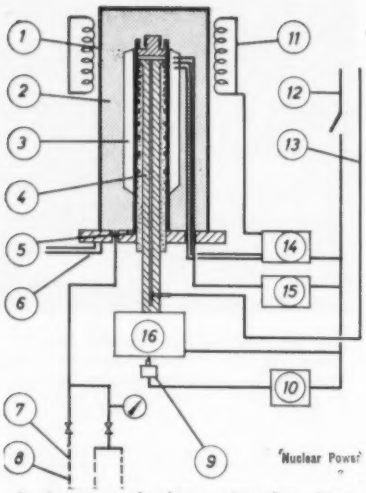
Heat transfer research

One important aspect of the Engineering Division's programme is the work of the Heat Transfer Section in the development of new designs of can and extended surfaces, aimed at improved heat transfer characteristics. Heat transfer rigs are being installed to study the basic requirements. Useful for comparing different can designs and for investigating effects which are not critically dependent upon Reynolds Number are two atmospheric heat transfer rigs, working on open cycle and using air. Blowers deliver air at approximately 75°C at mass flows up to 2 lb/s. The test sections, consisting of drawn cupro-nickel tube and drilled at various points along their lengths for pressure tappings, enable tests to be carried out with fuel elements stacked vertically, if desired. Maximum temperature at the test section outlet is 300°C. Power to each rig is supplied by a 112 kVA Foster transformer regulator with coarse and fine settings giving virtually stepless control of output voltage.

The limitations of the atmospheric rig so far as reactor design conditions are concerned will be overcome by the pressurized CO_2 heat transfer rig; this will operate at actual reactor pressures



The fuel element endurance rig provides a facility for testing half stacks of complete civil reactor fuel elements under steady conditions of CO_2 temperatures and mass flows, in excess of those in the civil reactors (Fig. 2)



A battery of three rigs has been constructed to simulate the strains endured by the cam body in the region of the welded and screwed fixing of the end closure (Fig. 3)

1 pressure vessel 2 CO_2 max. pressure (500 lbf/in²) 3 specimen 4 push rod 5 mandrel 6 cooling water 7 evacuation line 8 cardice converters 9 displacement transducer 10 recorder 11 furnace to heat specimen to max. temperature (525°C) 12 power supply 13 pressure rise operates motor cut-out only in leak detection line 14 furnace controller 15 multi-point temperature recorder 16 drive applying a strain rate = 10^{-3}, 10^{-4}, and 10^{-5} in/h

and temperatures with heat rates in excess of 20 kW/ft length in the test section. The main parameters are: maximum pressure 400 lbf/in², maximum outlet temperature 575°C, maximum inlet temperature 400°C, mass flow 6 lb/s at 300 lbf/in². The fuel element endurance test rig provides a facility for subjecting half stacks of complete civil reactor fuel elements to steady CO_2 conditions; up to 200 lbf/in² for mass flow and up to a temperature of 450°C. Quantitative data will be provided on creep deformation of the can extended surface and aerodynamic stabilizing devices to be anticipated after long periods of reactor service. The gas, circulating at rates up to 4·5 lb/s, will impose forces on the fuel element equivalent to three times those obtaining in the civil reactors (Fig. 2).

The vertical channel visual flow rig provides for the study of the behaviour of the coolant gas passing over the fuel element. Water is pumped round the circuit at the correct Reynolds Number and a coloured dye, or bleed of compressed air, is introduced to provide a visual indication of flow patterns.

Fuel element development

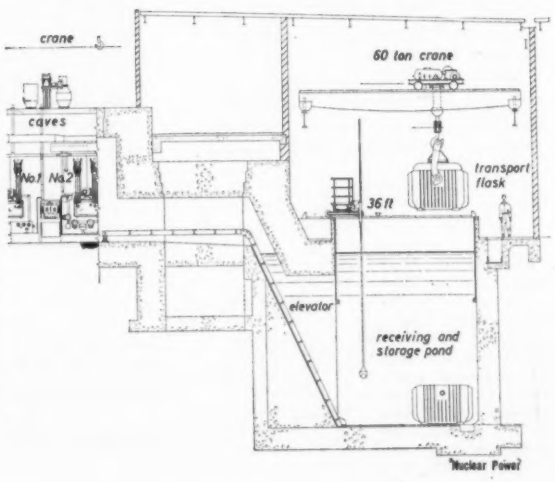
The work of this Section is concerned initially with the improvement and development of fuel elements for the uranium-magnox stations. Investigations will be carried out, however, on alternative types of future fuel elements. Effort will centre largely on the mechanical testing of complete fuel elements, cans and components under simulated reactor conditions of temperature, stress, strain, vibration and gaseous environment in order to assess more fully their behaviour in pile. The influence of actual environmental condition will be determined by the Materials Division in their study of irradiated fuel elements. Several rigs are being designed, each of which will enable a particular environmental condition to be investigated.

During irradiation, end growth of the uranium fuel severely strains the can body in the region of the welded and screwed fixing of the end closure. To simulate this condition is a battery of three rigs (Fig. 3). Contained within the pressure vessel, which can be charged at any desired pressure up to 500 lbf/in², is the test specimen, consisting of a short length of fuel can with its end closure. It is pressurized on to a hollow stainless steel mandrel on which anti-ratchetting grooves are machined, exactly as on the uranium fuel rod. The mandrel is supported on the top plate of the rig by a push rod which transmits through a conical loading pad at the top a constant strain applied by the unit below. This unit consists of a synchronous motor, worm reduction gear, change gears and a differential screw jack. Three slow strain rates equal to 10^{-3}, 10^{-4} and 10^{-5} in/h can be applied. A displacement transducer, fitted to the lower end of the jack, checks the constancy of the straining. The control panel provides for normal temperature control, auxiliary control, six-point temperature records and a number of strain gauge and thermocouple test points.

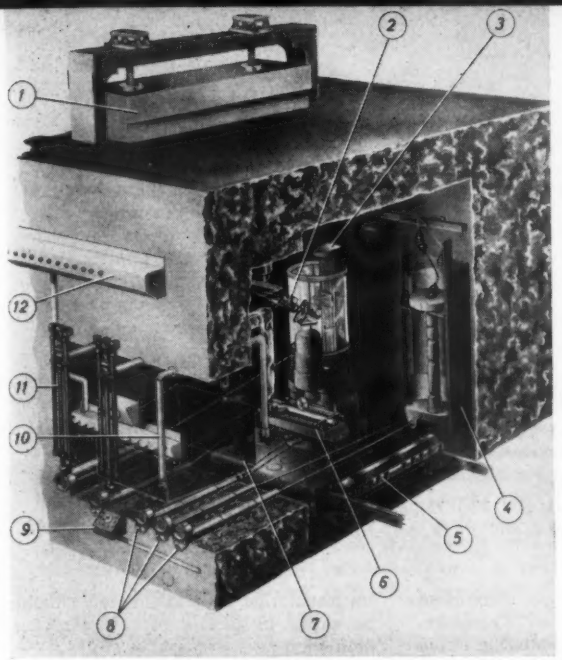
Rigs have also been designed to investigate the effects of thermal cycling, each of them being capable of subjecting a fuel element to automatic thermal cycling of various magnitudes and frequencies under correct pressure, temperature and end load conditions. Three rigs, designed by Babcock & Wilcox, will be used to look at the effects of comparatively large slow cycles, varying from ±5°C in a 5 min period, to ±50°C in a 20 min period. The working atmosphere will be either argon or nitrogen at pressures up to 300 lbf/in² and the maximum mean temperature of the element will be 450°C. Another rig, designed by Miles Electronics, is intended to cover the entire anticipated range of thermal cycling, ±1°C at a maximum frequency of about 8 c/min to ±50°C at the maximum frequency of about 10 c/h. Cycling amplitudes within this range can be independently varied. Transient heating and cooling of the element can be superimposed by manual control at any time during a test. The maximum cooling rate which simulates a 'scram' shut-down is 180°C/min. Analogue computer techniques will be used for cycling control. Two furnace vessels, each with its own control system, enable comparative tests of two fuel elements to be carried out simultaneously. The desired cycling conditions of temperature and coolant pressure are attained by regulating the heat input and the flow control valves. The onset of a can wall failure will be detected by a monitoring system.

Pressure vessel tests

As part of the reactor pressure circuit components development programme, tests will be carried out on scale model reactor vessels to determine the susceptibility of different vessels to various types of failure. Two series of tests will be carried out, the first for nozzle-shell junctions and the second for the skirt-shell junction. The model vessels for the first series will have about 20 standpipes at positions of maximum obliquity. Correct stress conditions will be induced at operating temperatures by internal pressure and applied



Storage pond, elevator tunnel and caves 1 and 2. Fuel elements from the power reactors arrive in stainless steel canisters packed in a 7 ft transport flask, weighing 43 tons. After the flask is deposited in the pond, the pond manipulator picks up the transport bottle from inside the flask and transfers it to the bucket of the elevator. It is then taken to Cave 1, where it is picked up by the power manipulator (Fig. 4)



When the transport bottle arrives in Cave 1 it is opened and the fuel element is dismantled ready for further treatment in subsequent caves (Fig. 5)

1 rising partition 2 power manipulator 3 three-saw slitting machine 4 bottle opening machine 5 elevator bucket 6 end cap/bridging machine 7 observation window 8 hand wheels 9 three-saw slitting machine panel 10 periscope 11 model 8 manipulator 12 pneumatic panel

loads to the standpipes to simulate restraint due to the pile cap and charge machine loads. In the second series, a load applied to the internal skirt will simulate the weight of the core. The creep distortion taking place in 20 years will be attained by a test of two months duration; this acceleration is effected by maintaining the vessel at elevated temperature. In the high strain fatigue tests, the vessel will be cycled at controlled rates between operating and shut-down temperatures once every 96 hours. Simultaneously, the standpipe loading will be varied to simulate the varying pile cap restraint due to contraction and expansion. The vessel will remain at shut-down temperature for two hours in every cycle during which it will be depressurized and brought back to operating pressure before raising the temperature.

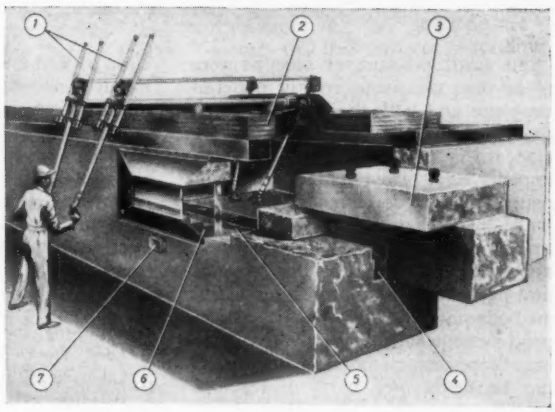
Post-irradiation studies

With the study of radiation damage problems as its primary concern, the Materials Division is directing its efforts towards a greater understanding of the various phenomena so that the behaviour of materials can be predicted and improved materials introduced. It is in a unique position for this kind of work being equipped with the most advanced installations for this purpose, for the acceptance of irradiated materials from all the CEGB nuclear power stations. As far as Hunterston is concerned, this aspect of research will be the responsibility of Windscale.

The layout and equipment have, therefore, been designed to receive fuel elements in transport flasks containing up to one million curies of radioactive material and to carry out examinations which involve the reduction to specimens whose activity is sometimes less than one curie. The fuel element is removed from the flask under water and taken by a conveyor through a shielded tunnel into the first suite of three caves (Fig. 4). The caves, which are formed of $\frac{1}{2}$ in mild steel with outer concrete walls over 5 ft thick, are separated by power driven, sliding partitions 2 ft 3 in thick. Observation from the front is through windows formed of lead glass filled with a zinc bromide solution. Concrete sliding doors at the rear give access to the maintenance area. Each cave is equipped with a pair of Savage & Parsons Model 8 manipulators; transport between the caves is by means of a GEC Mk. 1 power manipulator carried by a gantry which runs just under the cave roof.

After the cap is unscrewed and withdrawn on the bottle opening machine, the fuel element is transferred across the cave to the end cap/bridging machine which is basically a vertical mill with the usual traversing gear. It removes the bridges, struts and end caps, leaving only the cylindrical centre assembly of the element. Local transverse sections required for detailed examination can also be cut out. Preparation for the final stripping of the can from the element is completed by the three-saw slitting machine. The saws, which are spaced at 120°, are aligned to cut radially to a common centre. The second cave is equipped for metrology and radiographic examination. As the irradiated fuel element has a powerful blackening effect on the X-ray film, the radiography machine is designed to transfer the casette as quickly as possible between the shielded position and the exposure position. Operation is governed by an electro-pneumatic system linked to the controls of the X-ray generator. The metrology bench is capable of measuring any length up to 4 ft to an accuracy of 0·001 in diameter or thickness at any position or orientation to 0·0001 in, and extent and location of bow to 0·005 in.

The third cave contains modified



No. 1 cell is one of a block of nine, designed for machining, tensile testing metrology, encapsulating and other operations (Fig. 6)

1 Model 7B master slave manipulator 2 shielding plates 3 shielding block 4 electric railway 5 transport trolley 6 observation window 7 cell control panel.

leak detection equipment and a universal milling machine, which is similar to the end cap machine but has a more complex head with multiple spindles, two speeds, and indexing capabilities. Prepared samples are transferred from cave 3 to the cell block by an electric transport system. Eight of the cells are 5 ft × 4½ ft × 6 ft high, the ninth cell is of double width. Two cells are used for machining operations on test specimens, a third houses an Instron tensile testing machine and another is employed for metrology. The double cells are devoted to the steel specimen monitoring programme. Another cell is equipped with an encapsulating rig for sealing specimens in silica, and with furnaces for subsequent heat treatment. Finally, there are two general purpose cells in which short term experiments are carried out, and a cell for storage and general decontamination work. In line with the cells are the lead box suites designed for metallographic examination and testing, and small scale physical chemistry.

MAIN CONTRACTORS

Civil: TERSONS LTD *Ventilation and Heating:* G. N. HADEN & SONS LTD *Electrical:* N. G. BAILEY & CO LTD *Steelwork:* MODERN ENGINEERING (BRISTOL) LTD *Shielded Area—design and supply of equipment:* H. M. HOBSON LTD

Damage flux determinations, focusing collisions, direct and indirect methods of observing defects, irradiation hardening, fracture, corrosion, growth and swelling were discussed

Reactor materials and radiation damage

Report on a Conference organized by the CEGB Berkeley Nuclear Laboratories.

reported by: G. E. DARWIN, M.A., Babcock & Wilcox Ltd, and A. A. JOHNSON, Ph.D., Imperial College

THE EIGHT CONFERENCE sessions were devoted to specific reactor material problems and both the papers and the discussion were of a high scientific standard which illustrated well the impetus being given to the science of materials by the development of nuclear power. The first session was devoted to damage flux determination and was opened by Kinchin. For the cores of heterogeneous reactors, Monte Carlo methods now give results which are in good agreement with the limited number of experimental measurements which can be made. For parts of reactors outside the core, the Method of Moments is recommended. Direct measurement of the spectrum is difficult and calculation is to be preferred. It is possible that various semiconductor devices may become usable in the future, but at present, one must rely on threshold detectors. One of the most suitable of these is based on nickel and depends on the reaction —Ni-58(n,p)Co-58. In considering physical damage to metals, only neutrons and fission products need be considered and gammas can be neglected.

The second session, on displacement theory of damage, was notable for the discussion of the recent theoretical and experimental work on focusing collisions by Thompson. The incident neutron gives up a lot of its energy to the primary knock-on atom which itself subsequently displaces many other atoms from their lattice positions. The manner in which this occurs has recently been studied in an elaborate series of calculations using an IBM704 computer, at Brookhaven, and some of the results were shown as a film. These calculations are able to predict the initial pattern of lattice damage resulting from the sharing of the energy of the primary knock-on, but not the way this damage subsequently relaxes due to thermal effects. It turns out that the sharing of the energy of the primary knock-on tends to take place along close packed lines of atoms. Thompson has demonstrated this effect in measurements of anisotropic sputtering from crystals of gold bombarded by fast particles.

Direct and indirect methods of observing defects were discussed in the third and fourth sessions. Transmission electron microscopy has revealed dislocation loops in irradiated graphite and in some irradiated face centred cubic metals. These loops are believed to be formed by the collapse of platelets of vacancies or interstitials which have aggregated on close packed lattice planes. Although in principle it is possible to distinguish between the two types of loop, separation has only been achieved unambiguously for graphite, as reported by Williamson. Although similar studies have not yet revealed loops in neutron irradiated body—centred cubic metals such as iron or molybdenum, Mendelssohn has found some indirect evidence for their existence in irradiated niobium by measurement of thermal conductivity in the normal and super-conducting states. From the discussion, it seems that the occurrence of visible loops may depend on the dynamic equilibrium concentration of defects present during irradiation and hence on the dose rate, the bombarding particle and its energy. Beevers has bombarded molybdenum with protons and observed dislocation loops, the use of an accelerator giving a high rate of defect production. It was also suggested that loop formation should be easier in metals of low stacking fault energy.

Following the official opening by Lord Fleck of the CEGB's new Laboratories at Berkeley, 130 scientists from all over the world attended this conference. The success of the conference was due, to a large extent, to the organizers' strong-mindedness in keeping numbers small. Formal sessions were held in the Great Hall of Berkeley Castle and informal ones in the Laboratories

Bollmann showed the marked effect of total dose on stored energy in graphite. Above about 6×10^{20}n/cm² the relative importance of the 200°C annealing peak decreases. It tends to be replaced partially by steady annealing right up to the 1300°C peak. This result was ascribed to the increasing importance of defect clusters at high doses. Another indirect indication of damage is the increase in stress relaxation induced by irradiation. This is marked in graphite. The situation in metals seems less certain and early tests on aluminium and recent ones on zirconium have shown negligible effects. Recent results on stainless steels and nickel base alloys are different but more work is needed to establish the facts and the mechanisms. Only then can extrapolations be made to the actual working conditions of the various stressed components in a reactor. Konobeevski also reported irradiation induced stress relaxation in steel, nickel alloys and zirconium, the largest effect being in nickel.

It has been generally assumed that irradiation hardening (Session 5) may be analysed into 'source hardening' due to the condensation of point defects on to dislocations and 'lattice hardening' due to the interaction of moving dislocations with the stress fields of stationary defects or clusters. A convenient way to separate these two effects is to carry out tensile tests on the material and then to apply the Petch equation

$$\sigma_y = \sigma_i + k_y d^{-\frac{1}{2}}$$

where σ_y is the lower yield stress, σ_i the lattice friction stress, k_y is related to the stress to unpin a dislocation and $2d$ is the grain diameter. Much of the discussion was concerned with the definition of the various parameters and the effect of irradiation on them. Source hardening increases k_y while lattice hardening increases σ_i.

Results on the irradiation hardening of copper, mild steel, pure iron, and molybdenum are now available (Fig. 1). The deviation shown in irradiated molybdenum and the decrease in k_y in pure iron indicate the limitations of the Petch equation.

In Session 6, concerned with fracture, Hull reviewed the role of twinning in body centred cubic metals and concluded that twinning occurs in all of them and that the mechanism is similar. Twins may nucleate fracture at twin—twin and twin—grain boundary intersections and in a number of other ways. The importance of this aspect has not yet been established. Several speakers in the discussion debated Cottrell's prediction for the shift in ductile—brittle transition temperature (ΔT) for mild steel as a function of dose (ϕt):

$$\Delta T = k(\phi t)^{\frac{1}{2}}$$

k being a constant. Large doses seem to produce too large an effect but undoubtedly irradiation conditions such as dose rate are important.

Trudeau reported on the latest Canadian results on binary iron alloys and suggested that aluminium nitride might be disassociated by thermal spikes. Harries had found strengthening in irradiated aluminium killed steels as a result of annealing at 100°C. Such strengthening did not occur in silicon killed steels. Trudeau also thought that the increasing effect of irradiation on brittle fracture at increasing irradiation temperatures between 20 and 200°C was a strain ageing effect. Clearly these suggestions of strain ageing reinforce the need for irradiation tests on strained specimens and for clear separation of grain size and compositional effects. Ibragimoff gave some results on steels, irradiated to a large dose at 350°C. The hardening could be resolved in some instances into separate components due to the ferrite and the cementite. Complete recovery was found on annealing at 700°C. At 650°C, recovery seemed to be more rapid for the ferrite than for the cementite. A startling result was the reduction in electrical resistance found on irradiation, possibly due to a structural change in the cementite.

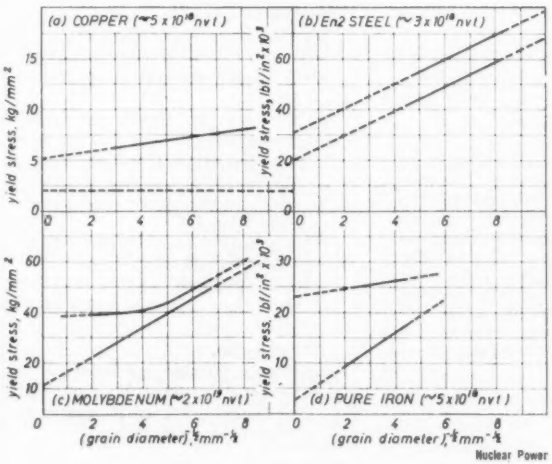
In the corrosion Session (7), Leach's outstanding paper considered the oxide film as an electrolyte and a semiconductor and suggested that alloys might have improved corrosion resistance due to the improved plasticity of mixed oxides. Buddery oxidized thin films of magnesium and showed that breakaway occurred on discrete spots, which were surrounded by networks of dislocations.

Session 8 covered growth (change of shape), due to both thermal cycling and irradiation, in a variety of materials. Pugh pointed out that while in graphite and beryllia, growth was largely due to a change in lattice parameters, in uranium, no change occurred. Further, annealing of neutron irradiated uranium has no effect on growth, whereas Rappeneau showed that annealing graphite at 600°C gave a 60% reduction in the perpendicular growth produced by irradiation at 150°C. Growth of uranium is now a well known phenomenon and recently Buckley has demonstrated growth in cadmium, zirconium, zinc and titanium, the growth rate decreasing with decreasing atomic weight. Even for cadmium the growth rate was more than a factor of 15 less than for uranium. Growth has not been detected in beryllium or magnesium. Thermal cycling has also been shown to cause growth in zirconium and in graphite, although in the latter material, stresses induced in manufacture are known to give an initial anomaly in irradiation growth and the two effects are probably related. Thompson found that proton bombardment of uranium caused growth which was an order of magnitude less than in neutron irradiation, and was recoverable on annealing.

Swelling of uranium was also discussed in Session 8. Greenwood tried irradiating first at a low and then at a high temperature, in the hope that the large number of bubbles nucleated initially would continue to grow uniformly and that the formation of large bubbles characteristic of high temperature irradiation would be prevented. In fact, the number of bubbles decreased and there was much discussion on the mechanism. Previously this had involved re-solution of the gas—a doubtful concept. Many people disagreed with the new mechanism based on dislocation movement. Eldred said that the concept of small bubbles being restrained by surface tension was supported by the Calder Hall elements swelling 2% after 2000 MWd/t. Pugh thought that, apart from occasional very bad results at above 600°C, swelling was worst at about 425°C. and Mercer's results of 8% and 3% after 3000 MWd/t at 400 and 500°C supported this. Mercer's uranium had endured a few cycles into the β phase with only a little cracking. Willis reported that α—β cycling of a zirconium-uranium alloy caused disastrous swelling. Pugh said that 50,000 cycles of ±15°C at 500–550°C had no effect on swelling in production uranium. Englander confirmed the good swelling resistance of 2% molybdenum alloys after 6000 MWd/t at 450°C.

It was unfortunate that neither of the two papers on control materials was discussed. Boron transmutes under irradiation, giving helium which can cause swelling in the same way as xenon and krypton do in uranium. Roberts annealed a boron steel control rod from Calder Hall and found that large amounts of swelling did not occur until about 900°C, which might be associated with the phase change in iron. Holden irradiated boron carbide, some transition metal borides and boron stainless steel, and found significant differences in swelling behaviour. The latter material was excellent apart from marked embrittlement.

It is hoped that the Proceedings of the Conference will be published in September.


(a) COPPER (~5 x 10¹⁸ nvt)
(b) En2 STEEL (~3 x 10¹⁸ nvt)
(c) MOLYBDENUM (~2 x 10¹⁹ nvt)
(d) PURE IRON (~5 x 10¹⁸ nvt)
yield stress, kg/mm²
yield stress, lbf/in² x 10³
(grain diameter)^-½ mm^-½
Nuclear Power

The effect of neutron irradiation on the yield stress/grain size relation for (a) copper ref. 1, (b) En 2 steel ref. 2, (c) molybdenum ref. 3, (d) pure iron ref. 4. In each case the upper line is that for the irradiated specimen (Fig. 1)

References

1. Adams, M. A. and Higgins, P. R. B., *Phil. Mag.*, 1959, **4**, 777.
2. Hull, D. and Mogford, J. L., *ibid.*, 1958, **3**, 1213.
3. Johnson, A. A., *ibid.*, 1960, **5**, 413.
4. Campbell, J. D., and Harding, J., to be published.

Recent changes have resulted in a more flexible approach to new research

Progress at Harwell

by J. SPENCER BURKETT, Assistant Editor, Nuclear Power

EXPERIMENTAL WORK of a fundamental nature is facilitated at the Atomic Energy Research Establishment, Harwell, by use of the precise energy beams from electrostatic accelerators. In addition, new information on nuclear structure and nuclear reactor mechanisms, as well as data on fast neutron reactions important to reactor design, has been made possible by the introduction of the tandem generator. Experiments in progress include the measurements of total cross-sections and shielding properties of reactor materials. Measurements are being made on helium, carbon, beryllium, lithium and calcium.

Associated with this work is the development of new techniques. A broad range magnetic spectrograph is an example; it measures most accurately the energy of outgoing protons in generator studies of nuclear structure (Fig. 1). A variety of small and compact solid detectors of silicon and germanium have also been developed which have an energy resolution as good as 15 keV and a pulse rise of 10^{-9} s. Precise timing electronics are needed, particularly for the type of measurements to be made on neutron inelastic scattering using the pulsed neutrons produced with IBIS. Directed towards the future use of NIMROD, the High Energy Group has designed new instruments such as a gas Cerenkov counter, combinations of scintillation counters and spark chambers, and beam profile indicators.

The improvement of reactor calculations—total cross-sections, fission cross-sections, etc., applied to reactor cores, moderators, fuels, and structural material—has now been made possible with the building of the Neutron Project, based on a linear electron accelerator (Fig. 2). Neutrons at a rate of 10^{18}n/s are produced by a pulsed beam striking a subcritical fissile target and are directed along 10 flight paths, up to 200 m long, to the various experimental apparatus.

Solid state studies have been greatly enhanced by the use of the intense thermal neutron beams from Pluto and Dido and much of the ancillary equipment developed is unique in this country. A time-of-flight spectrometer is used to study crystal dynamics; polarized neutron apparatus aids the investigation of the structure and properties of ferromagnetic materials, and a neutron diffraction device, more

CHANGES AT HARWELL

The Controlled Thermonuclear Reaction Division (formed 1958) transferred to Culham in 1960; the Accelerator Division (formed 1958) transferred to the NIRNS in 1961; isotope production and marketing transferred to the Radiochemical Centre, Amersham, in 1959; isotope applications development transferred to Wantage in 1959 (but still under the AERE); a Solid State Physics Division formed in 1960; a Research Reactor Division formed in 1960; the Reactor Division transferred to Winfrith in 1960—further transfer in 1961 to the new Reactor Group.

In the broad range magnetic spectrograph, protons from a target after travelling a circular path, strike a 27 in photographic plate. Protons having different energies strike different parts of the plate (Fig. 1)

EXPERIMENTAL FACILITIES

Reactors

GLEEP ('47) 3 kW graphite moderated reactor ($1{\cdot}4\times10^{9}$)[1]

BEPO ('48) 6 MW graphite moderated reactor ($1{\cdot}5\times10^{12}$)

DIDO ('56) 13 MW heavy water moderated reactor (2×10^{14})

LIDO ('56) 100 kW water moderated reactor (10^{12})

PLUTO ('57) 15 MW heavy water moderated reactor (2×10^{14})

DAPHNE (building) zero energy heavy water moderated reactor

Accelerators

166 MeV synchrocyclotron ('49)

5 MV electrostatic accelerator ('49)

12 MV tandem electrostatic generator ('59)

2 MV Van de Graaff generator (commissioning)

3 MV pulsed Van de Graaff generator (IBIS)[2](building)

50 MeV proton linear accelerator (at NIRNS)[3]('59)

7 GeV proton synchrotron (NIMROD) (building at NIRNS)[3]

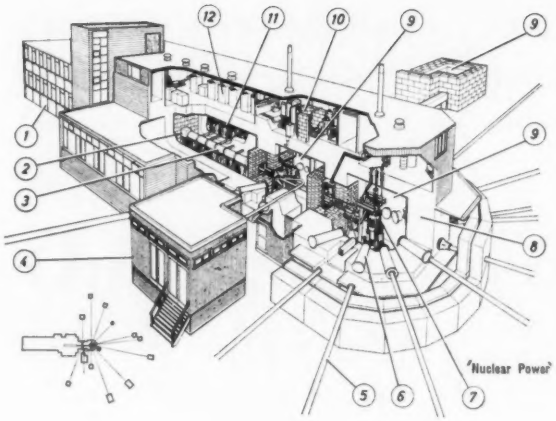
Neutron Project

28 MeV linear electron accelerator ('59)

[1] flux—n/cm²s

[2] Intense Bunched Ion Source

[3] National Institute for Research in Nuclear Science: Rutherford High Energy Laboratory



In the Neutron Project a pulsed neutron source is used for experiments employing the time-of-flight method (Fig. 2)

1 experimental laboratories 2 electron gun 3 linac 4 photonuclear experiments 5 neutron flight tubes 6 beam windows through concrete shield 7 booster target 8 concrete shield 9 target cells 10 target cooling circuits 11 Klystron valves 12 high power pulse modulators

efficient than X-ray diffraction, is being used for uranium compound studies.

Irradiation experiments

Over the last year, 80 new or replacement experimental assemblies were installed in Bepo, Dido and Pluto for the study of the physical and nuclear properties of materials for future reactors, for isotope production, and for basic investigations. The use of irradiation rigs for graphite experiments, for example, has been made possible by the introduction of hollow fuel elements for the Dido-type reactor. Carried out with accurate temperature control and in a sufficiently intense neutron flux, it is now possible to obtain, within two to three years, an irradiation dose equivalent to that encountered in the whole life of a power reactor. Information for the more advanced systems is being obtained, and improved types of graphite are under irradiation. Specimens are contained in each of three barrels independently controlled by electric heaters to close limits in the range 150-650°C. Cobalt and nickel monitors in each barrel enable the irradiation dose to be calculated. The barrels are suspended from a resin-iron shot shield plug through which pass the heater leads, thermo-couples, etc.

Boiling water research

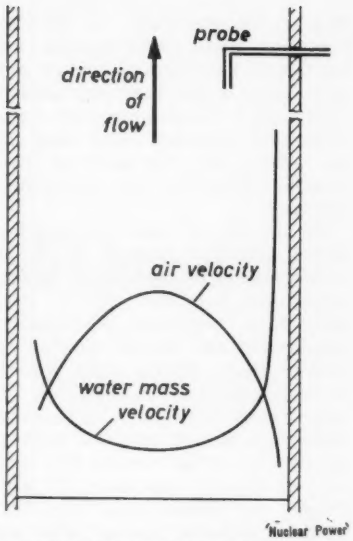
Basic studies are being made by the Chemical Engineering Division on two-phase flow and heat transfer in variants of boiling water systems, particularly in climbing film flow and spray cooling, and a number of rigs have been devised to obtain information on all the processes involved.

Characteristics of film flow are studied electronically by making the water slightly conducting and using electrical probes in the walls of the experimental tube; photoelectric devices are also used. For spray behaviour investigations, the rig used consists of a very long $1\frac{1}{4}$ in tube carrying mixtures of air and water. By means of traversing probe techniques, impact pressures are measured and samples withdrawn. From these measurements, separate local mass flow rates of air and water and their distribution across the tube are computed (Fig. 3). Specimen graphs show that the shape of the distribution varies according to the position along the tube.

To simulate conditions within a bundle of fuel elements in the study of burnout phenomena, a low-pressure heat transfer rig has been designed in which separately metered flows of water and steam are mixed and fed to the base of a test section containing a heated tube. This is surrounded by four copper bars, separated one from the other by ss spacers whose thickness governs the rod-spacing—which can be varied over a wide range. Conventional bar heaters let into the copper blocks provide the 'secondary heat flux' (Fig. 4). Similar heat transfer studies at pressures up to 1500 lb/in² are made in a large rig using, at present, a simple annulus. The heater element, 29 in long × 0·375 in diameter, can be supplied with up to 100 kW of power.

Reactor materials investigation

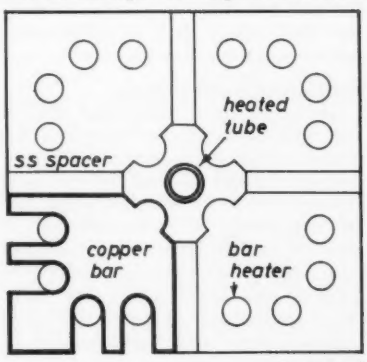
Metallurgical and related chemistry research, to a large extent, is directed towards the development of uranium dioxide fuels and plutonium ceramic fuels. Apart from improving existing fabrication techniques in the production of UO_2 pellets, dispersion type fuels and plate type bonded fuel elements are being looked at, particularly the development of a beryllium oxide and uranium oxide combination, and powder metallurgy techniques for the preparation of UO_2-ss cermet cores. Single crystals of UO_2 grown in an electrolytic process, are being used for basic studies on the determination of deformation and fracture mechanics,



In experiments on water entrainment in spray, it is shown that the shape of the air and water flow rate distributions across the tube are quite different from each other (Fig. 3)

structural analysis, chemical reactions and the mechanism and rate of xenon and krypton evolution from irradiated specimens. Neutron diffraction studies are to be made on the effect of temperature variations on structural changes in different combinations of uranium oxides. With the emphasis on ceramic materials, the lack of information about their atomic mechanisms, particularly the effect of sudden temperature changes, has sponsored a long term research programme.

Increasing work on plutonium has resulted in the development of improved glove box techniques. Projects under study include the incorporation of plutonium in uranium based alloys, cermets and ceramics and investigations into the stability of ceramic particles relative to the matrix. X-ray diffraction and microscopic techniques have been



For steam/water burn-out studies, the low pressure heat transfer rig contains a centre rod, electrically heated, surrounded by four copper blocks, to represent a bundle of fuel elements (Fig. 4)

evolved for the study of uranium-plutonium oxide phase changes and irradiation investigations are in progress. Looking at carbide fuels, development work is still at a very early stage; fabrication processes being tried out are only on the $\frac{1}{2}$ kg scale and cover sintering behaviour and densification processes.

On the use of steels for AGR thin walled cans, the principal concern is to minimize embrittlement and enhance oxidization resistance. Recent work indicates a preference for titanium stabilization and double vacuum remelting. Higher alloyed steels, possibly of the precipitation hardening type, are being looked at for use at temperatures higher than the AGR. Improvement in the integrity of ss fuel element end seals, working in CO_2 and steam, is being sought, and experiments have been made on different brazing alloys and

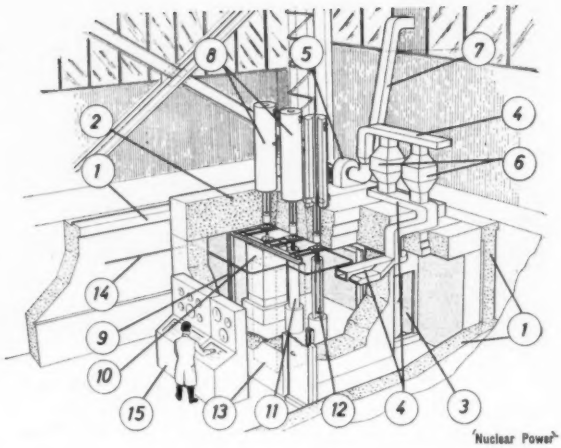
Specimen of glass produced, using appropriate inactive elements, during investigations on the effect of variations in combining materials (Fig. 5)

on a variety of seal geometries. Exploration work is also being done to ensure the impermeability of Magnox cans and to develop bonding techniques that will prevent the relative movement between the can and the fuel. Some progress has been made with a uranium-zirconium-magnesium combination.

Radioactive waste disposal

The treatment of radioactive effluent has been studied intensively over the past ten years by the Industrial Chemistry Group and much of the work has been carried to a pilot plant stage. For the treatment of liquid effluent of medium or low activity, ion exchange and chemical precipitation techniques have proven satisfactory. One plant which has a capacity of up to 1000 gal/h is a two-stage process and consists of sludge blanket precipitators followed by ion-exchange columns. A third stage is being investigated which will reduce the activity level by such a degree that the resultant liquor could be re-used for special purposes.

The 1000 curie pilot plant, designed to investigate the fixation of radioactive waste in glass, will be commissioned later this year (Fig. 6)



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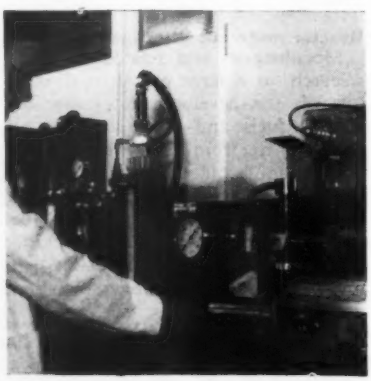
1 wall of pit 2 concrete biological shield 3 airtight access doors 4 ventilation ducts 5 extract fan 6 extract filters 7 extract exhaust to filters 8 vessel transfer coffins 9 steel supporting frame 10 furnace 11 oven 12 spare oven showing vessel in position 13 dotted lines indicate lead cell for active storage and feed vessels 14 off gas line to external scrubber system 15 control panel

The use of organic ion exchange resins for effluent decontamination has been hampered by the high capital cost involved in discarding the resins when exhausted and the use of large scale regeneration. A process using special regeneration techniques has now been developed, however, that consists of four columns containing, alternately, cation and anion exchange resins. The plant will be used to investigate the use of ion exchange materials and cost comparisons will be made with treatment by other systems. An experimental unit, offering considerable possibilities, has also been developed, using the principle of the electrodeionization of solutions by the passage through a mixed cation-anion exchanger bed.

The major problem of reducing to an inert and insoluble form, highly active fission products whose volume will increase when the UK nuclear power programme gathers way, appears to be near solution with the development to an experimental stage of a process that starts with flash evaporation and finally produces a non-leachable glass in disposable vessels (Fig. 5). While work at millicurie activity has shown promising results, it is not sufficient to provide the data necessary for the confident design of an industrial installation. Consequently, a 1000 curie pilot plant is being constructed to test the process actively, and to enable the study of decontamination factors up to 10^8 (Fig. 6). In this, the fission products, nitric acid solution mixed with slurried borax and silica, pass to a furnace where, after the liquid is rapidly evaporated and denitrated, the residual oxides are fused to glass. Steam and nitric acid vapours pass through a second vessel, which is identical to the first but contains a filter and absorber, and then to a condenser and a scrubber system.



The sodium flame test rig enables absolute filter testing to be completed in $\frac{1}{2}$ h instead of 3-4 h by other methods (Fig. 7)

Engineering development

Most of the scientific work of the establishment requires the support of the Engineering Division who are continuously devising new equipment and exploring new fabrication techniques. The Remote Handling Group, for instance, is responsible for the design and development of a wide range of equipment for working with radioactive materials. In the high activity handling field, standard machine tools recently adapted for remote control include a special purpose lathe for machining irradiated uranium which reduces work time from one day to 30 minutes. For materials difficult to machine by mechanical means, the use of the spark erosion machining process has been developed. For deep multiple trepanning, three cylindrical specimens 2 in $\times$ 0·4 in from a length of uranium fuel rod can be produced. To speed-up tests for absolute filters a prototype sodium flame rig has been developed that can test *in situ* and handles a 1000 ft³/min through-flow. It reduces the 3-4 h test time of the methylene blue system to $\frac{1}{2}$ hour (Fig. 7).

The rewards of on-load refuelling are too high to ignore, but the engineering and operating problems must not be under-estimated

On-load refuelling problems

by K. H. DENT, A.M.I.Mech.E., A.M.I.E.E.
Industrial Power Branch, UKAEA, Risley

REFUELLING CAPACITY

IT IS CONVENIENT here to express the refuelling capacity in terms of the minimum value of fuel average discharge irradiation in MWd/te which would be obtained on the particular reactor if the refuelling plant were operated continuously at its maximum throughput with the reactor at unity load factor.

The capacity must obviously be greater than that set by the discharge burnup of the design equilibrium fuel cycle. An allowance must be made for outages for planned and unplanned maintenance, and for the removal of prematurely failed fuel elements which would interrupt the routine operation. But more important is the need for flexibility to change from one fuel cycle to another, and to deal with peaks in a non-equilibrium cycle or during an initial delayed approach to a final cyclic condition—operations designed to improve the fuel utilization. A simple approach to equilibrium, for instance, cannot give a utilization factor for the first charge greater than 50% but this might be improved by half by suitable intermittent refuelling. The annual fuel budget for a large station may be £2-3 million during this period, so improving the utilization factor by even 1% is significant.

The required net capacity is influenced by the amount of standby refuelling plant to be provided and the speed and reliability with which it can be brought into operation. Typically, for a reactor designed for a mean discharge irradiation of 3000 MWd/te, a capacity equivalent to below 1000 MWd/te is probably economically worth having. Indeed, for a station likely to operate at long periods at base load, a good general guide is that the minimum handling capacity should exceed by a factor of three or four the design equilibrium fuel throughput at unity station load factor. This would enable the routine operations associated with an eventual equilibrium cycle to be carried out by day shift

THE EFFECT OF ON-LOAD REFUELLING

Refuelling can give rise to local and general changes in reactivity and to violent fluctuations in local temperatures. Some of the fuel and gas temperature measurements normally connected into the automatic reactor control system or trip circuits have to be temporarily suppressed. Provision may be necessary in the reactor control room to over-ride particular fuel handling sequences where necessary, and good communications must be provided between this main control room and the fuel handling control station. For on-load refuelling is an operation which is closely allied to the control of the reactor.

THE CASE FOR REFUELLING ON LOAD

After the short-lived poisons have reached equilibrium, reactivity in natural or near natural uranium rises with increasing burnup as fissile isotopes of plutonium build up, and then falls away continuously to values below the initial level as the effects of long-lived poisons and depletion in the uranium-235 begin to predominate (*1*). If a reactor is batch refuelled at a periodical shut-down as with the Calder Hall reactors (*2*), the total reactivity of the system will follow the same pattern. To obtain a high fuel burnup, excess reactivity must be available initially; this means the core must be larger, and the fuel investment greater, than would otherwise be necessary. This initial high reactivity would have to be taken up by movable absorber which would have first to be progressively increased in amount and then progressively withdrawn.

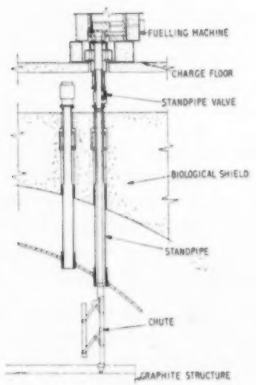
But now consider when individual channels are refuelled at different times to achieve and maintain a distribution in the levels of irradiation throughout all the channels in the core. Here the effective reactivity, being dependent upon the mean irradiation, will be relatively higher for any given value of channel discharge burnup beyond the peak on the point reactivity curve (*3*). The designer can use this higher reactivity in conjunction with radial flux flattening to produce a smaller core for any particular output requirement and fuel rating limitation. If the attainable fuel life is known with sufficient confidence, the required distribution in irradiation levels can be obtained by planned refuelling operations early in the reactor's life. Thereafter the effective reactivity would assume its equilibrium value; further adjustment of absorber would proceed at a steady rate. A further gain in reactivity can be obtained by fuel 'shuffling'. Re-arrangement of the fuel both within a channel (axial shuffling) and between channels (radial shuffling) can be shown theoretically to be of value (4, 5) but practical experience has yet to prove its overall worth.

These considerations lead to the conception of continuous refuelling with the reactor on load. The rewards are too high to ignore, for even the ability to remove a burst without shut-down must rate high for a commercial reactor. But the engineering and operating problems must not be under-estimated. A load factor of over 95% has, however, recently been achieved for a reactor at Calder Hall during a period of 12 months continuous operation before its annual shut-down for refuelling and maintenance (*6*).

whilst providing a reserve capacity obtainable through three-shift working.

CHANNEL ARRANGEMENT

The charge and discharge arrangement has a profound influence on the plant layout and must be considered at the early conceptual stages of the reactor design. Although the fuel handling arrangements tend to dominate the plant in the mechanical sense, the choice between vertical and horizontal channels for the reactor may be influenced more by space limitations, natural circulation performance, or preference in the method of support of the fuel or the major reactor components.



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The charge chute at Bradwell is inserted into each standpipe as required. The lower end can be moved outwards and the whole chute rotated to connect to any channel of the group served by the particular standpipe (Fig. 1)

In either case, four possible charge and discharge arrangements exist.

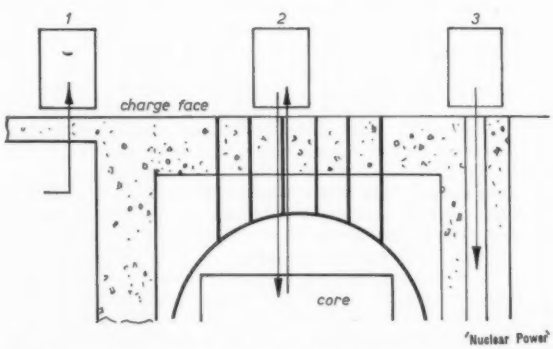
(a) Straight-through fuelling in the direction of coolant flow.
(b) Straight-through fuelling in opposition to coolant flow.
(c) Single-end fuelling at coolant inlet end.
(d) Single-end fuelling at coolant outlet end.

The choice between these is not the simple economic one of capital costs. The design of the refuelling gear cannot be considered alone, and the reliability of any particular arrangement in service, whilst of overwhelming importance, is not easy to assess.

With a reactor with horizontal channels, static friction cannot be relied upon to prevent the fuel elements blowing out where there may be ratchetting under thermally cyclic conditions or vibration-induced movement. With straight-through fuelling, a removable stop must be placed at the remote end of the channel if fuelling is in the direction of gas flow. Similarly, a catch or 'one-way' device is required at the near end when fuelling against the gas flow, as with the Marcoule reactors, to prevent blow-out during the refuelling operation. Straight-through fuelling has the potential advantage of allowing each fuel element to be moved progressively through the channel so that all elements are discharged at a similar burnup (*7*). Single-end fuelling of horizontal reactors has been previously neglected. The blow-out problem is difficult to solve when the refuelling is from the coolant outlet end and the logical choice is to recharge from the cool inlet end so that a simple fixed stop can be used at each channel outlet. This arrangement becomes attractive for the smaller, highly-rated reactor (*8*). With the vertical reactor, a further variable is introduced in the direction of gas flow relative to gravity. This choice is made principally from considerations of natural circulation and of the gas forces on the fuel elements and core structure under normal operating conditions, but upward flow introduces a possible blow-out problem which may be aggravated during refuelling. Gravity is the dominant factor, however, for fuel handling. Straight-through fuelling is costly and offers little practical advantage; the choice lies principally between single-end fuelling from either the bottom or the top of the core. Indeed, single-end fuelling is being adopted more and more on pressurized reactors whether vertical or horizontal.

The next distinction is between single-channel fuelling in which direct access is provided to each channel from outside the reactor, and multi-channel fuelling in which each access point is arranged to serve a group of channels. In each case, the access must be provided by standpipes or openings of some form in the pressure vessel, and these must pass through the biological shielding to enable direct access to be obtained to the closure feature at its outer end. Single-channel fuelling has technical advantages, among which are great simplicity of channel access, simplification of fuel temperature measurement and of on-load gagging adjustment, and the ability to handle a complete channel of fuel in a single string of rigid or semi-rigid form. It is expensive in other ways. Apart from the direct cost of the extra connexions, there may be a significant economic effect from the reduced strength of the pressure vessel brought about by the closely spaced openings. Multi-channel charging, however, has been used in vertical reactors to allow access to groups of between 16 and 80 channels from each standpipe. This gives greater freedom in the choice of lattice pitch, enables the charging standpipes to be widely spaced, and separate standpipes for control rods to be installed between them. Access is obtained to individual channels through a fixed cluster of guide tubes (*9*), or by a chute through the standpipe having a hinged section at its inner end which can be manipulated to connect with each channel in the group in turn (Fig. 1). Generally, multi-channel fuelling is adopted on large low-rated reactors; there is a tendency toward the single-channel solution on smaller moderately-rated designs such as the AGR, and toward the use of a single large connexion serving all the channels of a small highly-rated reactor such as DRAGON.

A further important factor to consider before choosing the basic refuelling arrangement is the method of gagging to give correct channel coolant flow. Where access is not provided directly to each channel, gags of fixed setting (or of setting adjustable initially only) are generally used. These are so placed in the channels that they can, if necessary, be replaced



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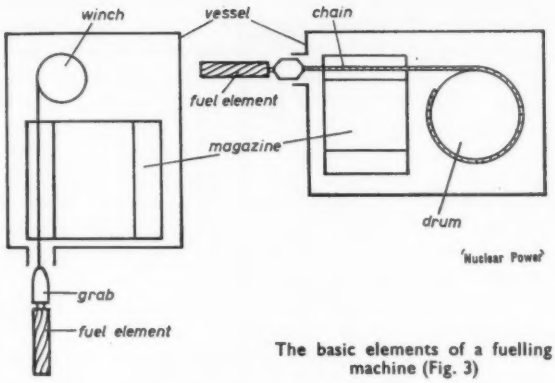
Three stages of fuel handling. 1 new fuel loaded in the fuelling machine 2 new and old fuel interchanged between machine and core 3 old fuel unloaded for processing (Fig. 2)



The basic elements of a fuelling machine (Fig. 3)

or removed for incremental adjustment. To avoid inadvertent mis-matching of the coolant flow with the channel power, it is best not to disturb the gags during routine refuelling. This principle is difficult to meet with straight-through fuelling but generally can be achieved with single-end fuelling by positioning the gags in channels remote from the access end; this solution is generally used in the vertical UK power reactors.

BLOW-OUT AND FALL-BACK

The twin problems of fuel element blow-out and fall-back are of great importance in a vertical reactor and represent uncontrolled movements of fuel.

With the vertical reactor with upward gas flow, removal of fuel elements progressively from the channel reduces the coolant flow resistance. But since there are many channels in parallel this has a negligible effect on the total core pressure drop. Therefore the mass flow in the channel concerned increases, and if this is sufficient to make the drag on the remaining fuel elements exceed their weight, they will blow out of the channel; or conversely, it would be impossible to lower them into the channel if refuelling from the top. There is a similar problem with a suspended fuel element grab itself, and with gags and other channel components which are not locked in position or which need to be handled on load. A number of possible solutions can be considered.

Improvement of the weight-drag characteristic is of marginal value only since it is of use only when the critical number of fuel elements for blow-out is already, or can be reduced to, one. Assuming the fuel element cross-sectional geometry to be fixed by the requirements of reactor performance, then the only adjustment which could be made is in length which may well be limited by other considerations.

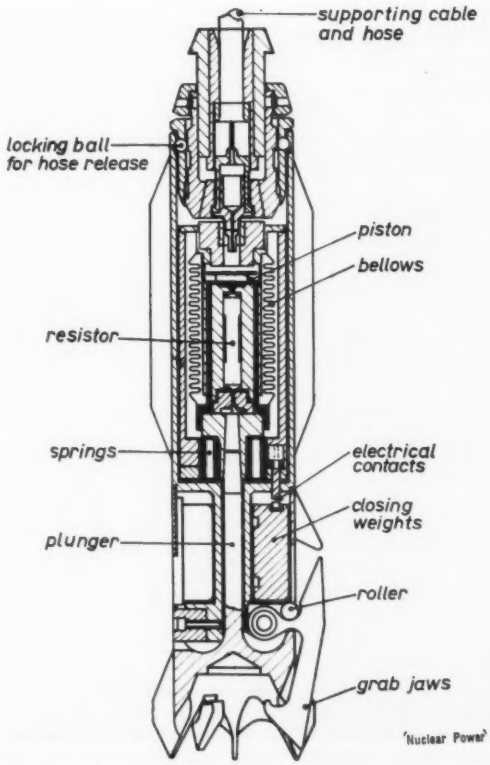
If the critical number of fuel elements occupies only a small fraction of the channel length at the cool end, gas can be by-passed over that length to give a smaller relative increase in drag on the fuel elements in that section when the remainder of the channel is empty. In its simplest form, the by-pass could consist of a local enlargement of the channel bore—although a variation in channel diameter is undesirable from other aspects. When used together with refuelling from the top, it would also be necessary to avoid levitation as the fuel element passes through the normal upper portion of the channel; this can be accomplished by selection of a suitably high combined weight-drag ratio of the fuel element and grab together.

Variable gagging to control the gas flow in the particular channel during refuelling can take several forms. The simplest is to take all the channel flow through a portion of the charge chute so as to increase the effective channel friction factor; but the need to limit the consequent initial temperature rise makes this of value only in a marginal case. A variation is to have a two-stage gag in this portion of the chute such that gas flow is restricted one degree further before the critical number of fuel elements remains. Adequate interlocking of the gag is probably impossible, so the fuel temperature rise under the worst flow conditions brought about by maloperation must still not be dangerous. Other similar unattractive variations are possible. Control can alternatively be achieved by passing the entire channel flow through the fuelling machine or some temporary external circuit containing a constant displacement pump or metering device. Failure of this circuit, however, could lead to immediate and serious overheating in the channel concerned without the condition necessarily being recognized by the reactor protective system. This lack of inherent safety is difficult to combat.

Safer, but more costly, is using a permanent flow restrictor in each channel. This reduces the ratio of flow resistances of a full and a partly empty channel and so allows only a smaller rise in mass flow as a channel is emptied. The price, a higher coolant circulator power and reduced station efficiency, may be tolerable in certain cases.

These are solutions to an essentially transitional problem. They apply only to one phase and range of ratings of any particular reactor system wherein fuel ejection occurs with a partially empty but not with a full channel.

The problem of a fuel element falling back into the core during handling is unfortunately not amenable to such technical solutions. Fall-back should be eliminated as far as



Typical design of a fuel element grab using pneumatic operation and electrical signalling (Fig. 4)

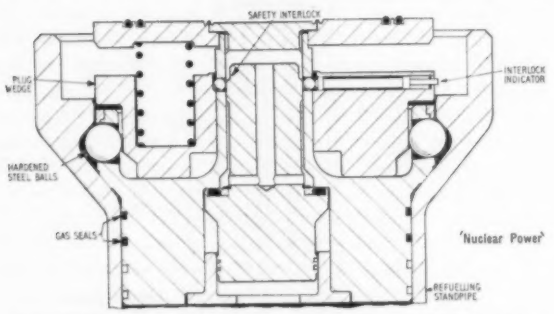
possible by sound design and through the use of mechanical and electrical interlocks. But this is not enough. A fuel element may inadvertently fall through a structural failure of the handling gear or of the element itself. Suitable precautions must therefore be taken in the design of the element and the support feature in the bottom of the channel both to prevent damage to the core structure and, even more important with the reactor on-load, to prevent local or general overheating in the channel arising from damage to the heat transfer surface or restriction in the gas flow.

MACHINERY DESIGN

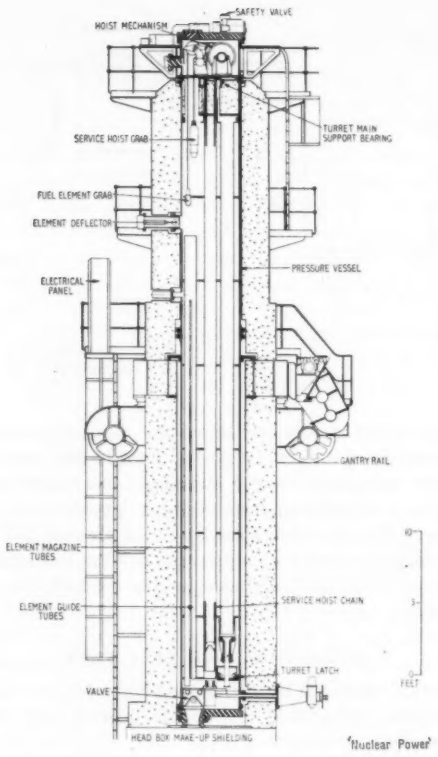
The refuelling plant's essential function is to place the fuel elements safely in their correct positions in the core and to remove them subsequently on demand. Withdrawal of any particular element may be demanded either through the operation of the chosen fuel cycle, or occasionally as a result of a metallurgical or mechanical failure. The plant's ability to discharge reliably a failed or distorted fuel element is a measure of its success: the design should not be dependent upon a high dimensional stability in the fuel which may not be maintained after long periods of irradiation.

The design adopted in the UK entails three separate handling stages (Fig. 2). First, the new fuel is loaded into the fuelling machine; second, the machine is connected to the reactor and the new and old fuel elements are interchanged between machine and core, and third, the old fuel is unloaded for processing as necessary, prior to storage. The criticism is often made that handling by these separate stages is ill-conceived and that fuel replacement should be more automatic and more continuous without repeated movements. In fact, the number of fuel elements to be replaced is not high by ordinary standards—about 10,000 per year for a large uranium-magnox reactor. And the segregation of operations gives distinct advantages. Handling of individual fuel elements within the machine is restricted to a few simple movements which are virtually repeated at each stage, so that the mechanical complexity is minimized. In addition, the machine and reactor vessel form a single sealed unit whilst the elements are being interchanged in the core; thereafter, the machine can be kept sealed and the irradiated elements held under a controlled atmosphere up to, and even during, the time they are unloaded. Each operation is distinct; the possibility of an accident is reduced and its effects confined.

The detailed functions of the machine must now be stated. It is necessary to consider all possible modes in which the fuel element concerned may fail or distort, and to decide which of these are to be covered by the routine handling arrangements.



A typical design of a standpipe sealing plug in which the coolant pressure loading is carried on the balls which engage an internal groove in the standpipe. A safety interlock in the centre allows the balls to be retracted and the plug removed only when the pressures above and below the plug are balanced (Fig. 5)



The fuelling machine at Bradwell weighs 400 tons and is mounted on a travelling gantry (Fig. 6)

It may be convenient to provide special grabs for use with the machine in certain cases. Although on-load television is now becoming available (*10*), it would, in general, be deemed advisable to remove any particularly damaged fuel off load, and the provision of separate equipment for this purpose may be economic. There are other items which can sometimes be handled economically by a refuelling machine if suitably designed. These may include control rods, and more particularly, items which go into individual channels, such as absorber elements, gags and irradiation specimen containers.

The basic operation of a machine for single-end fuelling is the transfer of new and old fuel elements between the core and a magazine within the machine. Each element (or string of elements) must be handled by an operating head or grab. This can be suspended by a winch-driven flexible rope or cable in the case of a top-charge vertical reactor (Figs. 3 and 4), or attached to the extremity of a semi-rigid chain in other cases (*8*, *11*, *12*). Where a charge chute is used, this can be handled either by the fuelling machine itself (*13*) or by a separate ancillary machine (*14*, *15*, *16*). The grab must be designed so that it does not cause an appreciable reduction in the coolant flow when it enters the channel. In either case, the chute will, in general, only be needed in conjunction with the fuelling machine and can be operated therefrom. Becoming more common is, in fact, the comprehensive type of machine which handles the chute and carries out the complete refuelling operation on one or several channels while connected once to the reactor.

The magazine and grab and other mechanism of the fuelling or the ancillary machine must be contained within a vessel capable of being pressurized and connected to the

reactor circuit. If it can be pressurized while disconnected from the reactor, the machine vessel and any other such component must be protected by a relief valve arranged to discharge through a suitable filter. Excess pressure in the reactor must not, however, be relieved through this safety valve! To avoid this it is best to construct the machine vessel for a design pressure not less than 1·1 times the normal reactor pressure, and at least equal to the highest blow-off setting of the reactor safety valves or the highest pressure within a sealed machine which could arise from after-heat of the discharged fuel or other causes. The machine safety valve should then be set to lift at 1·05 times the machine design pressure. Arrangements should be provided to purge the interior of the machines of air before they are connected to the reactor. The blow-down from the machines is best passed through the filters and iodine absorption units of the normal reactor blow-down line.

The connexion between the fuelling machine and reactor standpipe must allow free movement of the standpipe resulting from the maximum possible changes in temperature or pressure. A retractable pressure sleeve, having a limited lateral flexibility and forming a piston-type seal with the standpipe, is simple and reliable. With the two pressures balanced, valves in the standpipe and machine can be opened, the shielding plugs withdrawn from the standpipe and the refuelling operation can start. Valves fitted to each standpipe are expensive and bulky. Sealing plugs with retractable balls which engage in an annulus in the bore of the standpipe and require no special orientation (Fig. 5) can frequently be used instead.

The source strength of irradiated fuel when just discharged into the machine may be many hundreds of kilo-curies. The operators must be protected from this gamma radiation, as well as gamma and neutron radiation streaming from the core when the shield plugs are removed, to keep within the maximum permissible doses prescribed (*17*). Local shielding on the machine is the only satisfactory solution since it must be possible to approach a loaded machine in case of breakdown. Concrete, or combinations of a neutron shielding such as ' Hydroboard ' and gamma shielding such as cast iron, are commonly used (*18*).

A large fuelling machine with its shielding will weigh several hundred tons. With a horizontal reactor it is generally mounted on a traverser on an elevating platform so that it can be moved between each access nozzle on the vertical charge face and the various service points. With a vertical reactor the machine can either be mounted on a travelling gantry (Figs. 6 and 7) and see (*19*), or handled by an overhead travelling crane so enabling several machines to operate on the charge face at once (*14*, *16*).

Where the grab and cable, and perhaps the charge chute, spend a significant time in the neutron flux from the core, they will themselves become active. This activity is likely to be sufficiently high to make the interior of the machine unapproachable for routine operations, and the loading of new fuel into the magazine as well as the unloading of the old is best carried out as a remote operation by the machine itself. The fuel should be transferred to the storage pond by the simplest and most reliable means, without unnecessary intermediate handling, and with the minimum delay.

In designing the fuelling machinery, robustness and maximum simplicity should be the aim. The design should not place reliance at any point on a high dimensional accuracy of the irradiated fuel. Accessibility of the key components is essential and prime-movers should, for preference, be mounted external to the pressure vessel and shielding; where this is not convenient, drive assemblies are best arranged as complete easily replaced units. In each case a directly accessible manual drive should also be provided so that important sequences of operations can be completed should either the prime-mover or its power supply fail. Provision must be made for viewing the interior of the machines by optical devices or by closed circuit television, either permanently installed or capable of being introduced when required. Normal good engineering practice should not be overlooked. In particular, careful attention should be paid to lubrication of moving parts: this subject has been much studied over the last few years (*20*) and a number of greases which retain their properties well under neutron and gamma radiation (*21*) are commercially available.

To ensure good reactor availability, the required refuelling capacity should be split between two or more machines, or a complete standby fuelling machine be available ready for use, so that at least a failed fuel element can be removed from the reactor when one machine is undergoing routine or breakdown maintenance. A good maintenance facility is a sound investment. Active grabs and other components must be handled, and test facilities are needed to calibrate the equipment, check its operation, leak test the pressure parts and check safety valve settings.

FUEL TEMPERATURE CONTROL

The designer must be continually aware of the need to keep within acceptable limits the temperature of the fuel elements his plant is to handle.

The temperature expected to be reached by the element at all stages in the handling cycle under both normal and fault

The fuelling machine at Bradwell (Fig. 7)

conditions should be determined. Special cooling arrangements should be made where necessary in the chute or fuelling machine to deal with the after-heat of the irradiated fuel. It is best that the discharged fuel be kept within some form of containment until it is placed in the pond, preferably in an atmosphere of the reactor coolant rather than air. To avoid the risk of ignition of finely divided uranium, metallic fuel elements should be kept below 275°C in the presence of air, or a similar appropriate temperature when in a pure coolant atmosphere (say 525°C in CO_2).

Severe temperature cycling of each fuel element during charging can give high strains in the cans and should be mitigated as far as possible. Thermal cycling of all the fuel in the core can occur through flux changes brought about by grab insertion and fuel movement. Attention should be paid to absorption cross-section of grabs and similar equipment to ensure that such cycling is kept at an acceptable level.

It is a cardinal principle that cooling of any fuel channel should not be jeopardised by the refuelling arrangements. It is generally safer when the channel being refuelled is cooled by the normal gas flow provided by the main circulators; this will minimise the risk of over-heating in the channel concerned. This local over-heating would not be significantly suppressed by a negative temperature coefficient of the fuel, and might go undetected by the normal reactor instruments without an alarm or reactor trip. Both the design of the core and the fuel handling gear should inherently prevent a fuel element being loaded into any channel in which the coolant flow is not at least matched to the power that would be released therein.

Where permanent temperature instrumentation is not provided in each fuel channel, the operator needs some indication that a channel has been re-loaded satisfactorily and is operating within an acceptable temperature band. This assurance can be given by monitoring the channel continuously during refuelling by the normal burst cartridge detection gear, and by checking the channel gas outlet temperature by a device introduced temporarily as part of the fuel handling equipment.

MACHINE CONTROL

True manual operation of the heavy fuelling machinery of large power reactors is impractical and power drives are needed for almost all routine operations. These enable a system of centralised control to be used, co-ordinating the functions the equipment has to perform and giving the operator easily assimilated information.

The control centre may be either local to the machines or away in a special control room. The choice is largely influenced by the design of the fuel handling system and, in particular, by the number of separate machines to be controlled. Generally, the greater the number and diversity of machines, the easier it is to incorporate the control equipment on each machine. Remote control, however, has several attractions. Greater freedom in the design of controls and instrumentation is permitted, and the control room can have extra shielding and be situated in a non-contamination area.

To what extent should operation be made automatic? Full automation would rob the operator of all responsibility and the exercise of judgment in the use of the equipment. To deal satisfactorily with any untoward event the operator must be alert and fully aware of the exact state of the operation: to keep alert, his mind must be occupied with a control job having a degree of interest and variety. Full automatic sequencing of complete refuelling operations involving the control of complex machinery is therefore probably far from ideal. However, if every event were manually operated, the operation could be both tedious and slow, and indeed unreliable. The most satisfactory solution is probably to carry out all the minor sequences of one operation (such as the transfer of a single fuel element from machine to channel) by automation, and to provide the operator with a varied set of controls, well designed (*22*) in accordance with the principles of ergonomics, for the initiation of each such major element of operation. Individual control of each sub-operation also needs to be provided, both for use in testing the equipment and in emergency.

The operator depends upon his instruments to tell him of the state of progress of the fuelling operations, and he must be provided first with the minimum information necessary to control the equipment safely and efficiently. For ease of assimilation much of this information can be presented by on-off indicators, instruments should be correctly designed and positioned in relation to the controller which affects them (*22*), and the presence of faults should be drawn to the operator's attention by suitable alarms. Additional quantitative information should, however, be provided to enable any abnormal situation to be assessed and safely dealt with. In particular, quantitative data on the position of the grab, its loading and its state are invaluable and well worth the extra complexity entailed in this component.

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A preliminary design has been made at Argonne National Laboratory for a radiation damage research reactor to provide a high energy neutron flux with low thermal neutron and gamma ray background

Basic radiation effects reactor

THE DESIGN OF the Basic Radiation Effects Reactor, BRER, arises from two main requirements : (1) a fairly high-level, high-energy neutron flux with low thermal neutron and gamma ray background, and (2) a neutron energy spectrum peak variable in the 10–1000 keV range. The first requirement is met by using a fast reactor and the second by surrounding the core with a large lead reflector. Calculations have shown that there is a 500 keV peak in the reflector region close to the core. The spectrum is broadened and the peak lowered further out. The shape of the spectrum can be influenced by replacing segments in the outer part of the reflector by elements with lower atomic numbers such as aluminium, iron and zirconium. Other calculations have shown that the gamma ray heating in the reflector is much reduced compared with thermal reactors having similar fast fluxes. Consequently it will be possible to carry out irradiation experiments with fluxes as much as 100 times higher but giving the same amount of gamma heating. This is important for cryostat irradiations where heat removal facilities are limited.

Core

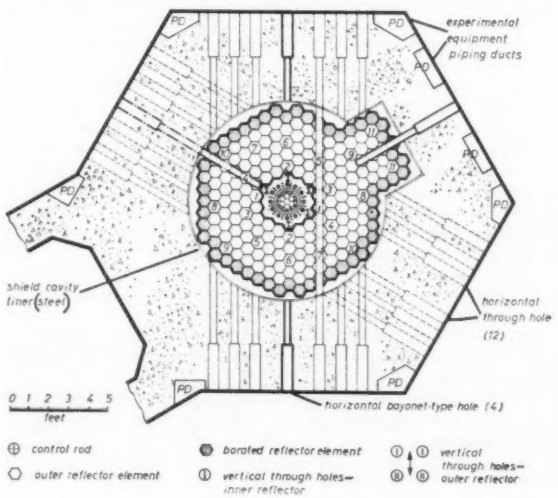
The BRER has a small NaK-cooled fast core surrounded by a segmented radial reflector. The secondary heat exchanger, also using NaK, rejects heat to atmosphere using an air-blast cooler. The core is made up of small diameter uranium-zirconium rods in a close-packed triangular pattern. The core design itself is based on the EBR-1 Mark III core with suitable features included to ensure rigidity of the elements to eliminate reactivity changes occurring when the rods bow due to rapid power oscillations. The overall length of a rod is 210 cm (83 in); a long steel handle is attached to the upper end for fuel handling purposes and a short zirconium extension at the bottom for aligning the rod in the grid plate. The 12 control rod guides are as close to the core as possible. The control rods are steel tubes 5·1 cm (2 in) dia. filled for the most part with lead. Additional reactivity control for emergency is by a safety plug immediately below the core which can be lifted up into the reflector by air pressure. Instrumentation and fuel handling are similar to other heterogeneous systems.

REACTOR DATA

Reactor power	1·0 MWt
Power density, max.	0·21 MW/l
Core volume	6·9 l
Fuel rod dia.	1·03 cm
Fuel alloy	U-235+2% Zr
Cladding (0·051 *cm thick*)	Zircaloy-2
Number of rods (7 *assemblies*)	252
Fuel loading, U-235	60 kg
Max. centreline temp.	285°C
Max. surface temp.	210°C
Hexagonal reflector elements	Lead+steel cladding
Number of reflector elements	211
Coolant	NaK
Flow rate	11·4 l/s
Temp., inlet–outlet	66°–177°C

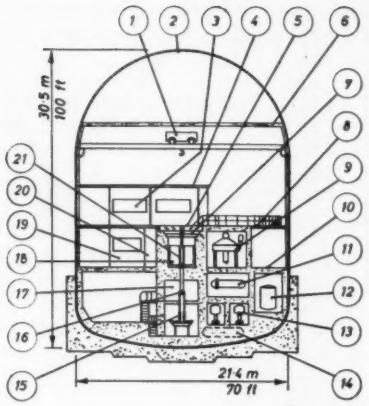
EXPERIMENTAL FACILITIES

Peak neutron flux	3×10^{13} n/cm² s
Predominant neutron energy range	10–1000 keV
Nominal hole size	10·8 cm
Horizontal holes	
Through	12
Thimble	4
Vertical holes	
Through	25
Thimble	2



Plan view of core, reflector and shield

'Nuclear Power'



'Nuclear Power'

Reactor building elevation

1 Crane; 2 Containment shell; 3 Control room; 4 Operations office; 5 Removable top shield blocks; 6 Missile shield; 7 Rotating shutdown shield; 8 Balcony; 9 Shutdown cooler; 10 Main floor; 11 Heat exchanger; 12 NaK supply tank; 13 NaK pumps; 14 NaK drain tank; 15 Control rod drives; 16 Safety plug drive; 17 Sub-reactor room; 18 Reflector; 19 Laboratory; 20 Entrance; 21 Core vessel

Coolant

Coolant is eutectic NaK (78% K, 22% Na m.p. −11°C); it enters an annular space between the vessel and the seven fuel assemblies, and then reverses direction, flowing up through the grid plate and around the fuel rods. From the heat exchanger, the NaK flows to a 750-gal. supply tank in the basement. The exposed surface of NaK is blanketed with nitrogen to prevent reaction with air. No special precautions are needed for removing oxides and the supply tanks act as large cold diffusion traps. The rate of temperature rise on loss of coolant flow due to pump failure is slow enough to allow a switch to be made to the spare primary pump. There are emergency battery and motor supplies in the event of a power failure. For long-term shut-down, a thermal convection loop is used which is brought into operation via a valve, the valve to the primary heat exchanger being closed. The reflector is air-cooled.

Facilities

The experimental facilities are in the reflector region. The inner part of the reflector is fixed and made of lead. The outer part is made up of removable hexagonal assemblies to provide the required variation in neutron flux spectrum. The outer ring of 54 elements is semi-permanent and contains dispersed boron to absorb thermal neutrons from the shield. All of these outer elements are potential experimental positions. The arrangement of the core and facilities is shown on the accompanying diagram. Temperatures in the experiments will range from 4°K to 1000°C, the lower temperatures being obtained by liquid helium and nitrogen and the higher ones by electrical heaters.

The reactor is in an air-tight steel containment vessel which will withstand the energy release from the reaction of a significant proportion of the coolant with air.

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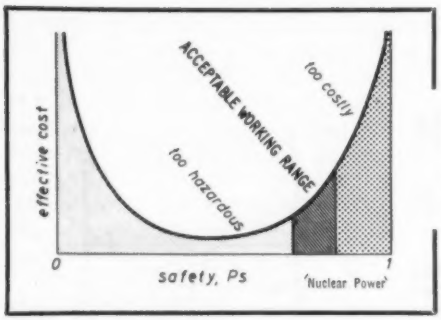


All safety, rather like velocity in the Special Theory of Relativity, is relative. In practice we must always resort to some safety standard which incorporates a measure of acceptable, calculated risk.

The safety of research reactors

by J. F. CROFT, B.Sc., Ph.D., Health Physicist, AEE, Winfrith

THE PROBLEMS of reactor safety derive principally from the radioactivity of the fuel, the fission products generated within them and the penetrating radiations emitted.

The fission chain reaction is an inherently unstable one, and for this reason its use involves an inevitable potential danger. However, under carefully defined conditions, it can be controlled, and will exhibit a predictable measure of self-stability, expressed by such factors as temperature, pressure and void coefficients of reactivity (see Fig. 1). It is axiomatic that the greater this self-stability characteristic, the less exacting will be the requirements of the associated safety mechanisms.

Fission products containment

Specific containment levels may be defined, as for example those supplied by the fuel cladding, the primary coolant circuit or associated clean-up plant, the reactor enclosure and any additional containment building. The stringency of the selected containment levels must be specified by a systematic analysis involving a number of variables which include the power level, and hence total fission product inventory of the core, the potential accident conditions inherent in the reactor design and the nature of the reactor site. The authorised maximum permissible radiation exposure levels (*1*, *2*) must be related to the climatology and population distribution of the neighbourhood. The limiting case may not in some circumstances be that of direct radiation or inhalation hazard to persons, but of ingestion of radiotoxic materials via the ground pollution of agricultural land. A well-known example is that of milk pollution by I-131, as illustrated by the Windscale incident (*3*). The specified maximum permissible containment leakage rate must be related to both normal working and accident requirements, and will be the lowest level which can be achieved whilst retaining a reasonable balance between safety and cost.

Reactivity requirements

(i) The available excess reactivity invested in the core should be limited always to the minimum practicable value. Hicks and Eltham (*4*) define an ' EVERSAFE ' low power research reactor as one in which the core, after assembly and confirmation of the predicted reactivity balance, is such that a power excursion of sufficient severity to melt the fuel is impossible. This is a criterion which is satisfied if the total excess reactivity in the core is less than the least step addition of reactivity which will melt any part of the core, assuming this has been estimated correctly.

A more appropriate description of such a system would be that of ' GILT-EDGED ', i.e. one which is safe by (fuel) investment, for whilst the concept is practically useful, the term ' eversafe ' could be misleading, implying, as it does, that an infallible system can be devised. For example, even if an estimated safe restriction be placed on the number of fuel elements which may be placed in the core, there remains the possibility of using fuel of too high enrichment. Though

By a suitable multiplicity of safety and control mechanisms a reactor can be made virtually infallible—**provided it is correctly assembled and operated.** It is difficult to conceive of a fully automatic system from which the independent judgment of a human operator is entirely excluded. Conjointly with this, we must recognize the unquestionable absence of completely infallible human beings. Here there is a need for optimization, since added complexity of control mechanisms for improved mechanical reliability will produce a corresponding operational complexity which may itself be conducive to error. Experience has shown that careful pre-planning can effectively increase safety without unduly prejudicing convenience in operation.

Basic aims

1. The operator must be able at all times to accurately diagnose the physical state of the reactor.
2. There must always be sufficient quick acting negative reactivity available to counter any developing fault condition.
3. The operator must never be compelled by the design to take a wrong action or be prevented from taking the correct one.

in some instances this may be virtually inconceivable, it nevertheless illustrates the point that human error is always possible at some point in the safety chain.

(ii) All components contributing to the reactivity balance of the system should, as far as possible, be so sub-divided and independent as to eliminate the possibility of a hazardous transient resulting from the mishandling or failure of a single component.

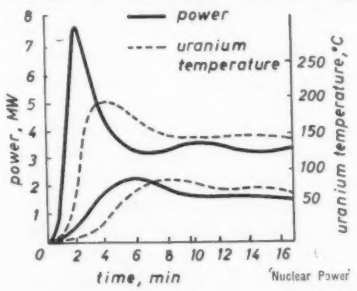
This requires that a systematic analysis be made of the increments and rates of reactivity addition which may occur on the system, either deliberately or by accident. This will include such items as the addition of fuel, the removal of absorbers, temperature and voidage changes, together with possible changes in disposition of the core or reflecting system. This analysis must take into account the cumulative effect of any series of consequential changes.

(iii) The available rate of reactivity addition, via the control system at start-up, must be so limited that in the event of a failure to terminate this addition correctly, the resultant transient shall not be hazardous. This is particularly important in those systems for which a large excess reactivity investment is necessary to overcome poisoning and temperature effects. Such a limitation must be related to the fitted instrumentation, and where this is of the high standard demanded on UKAEA reactors, with a suitable multiplicity of trip functions and associated channels, it is appropriate to base the assessment on operation of the slowest-acting nucleonic trip function.

(iv) Sufficient reactivity control must be invested in the control and safety systems to ensure that it will be at all times, and in all foreseeable circumstances, possible to shut down and hold down the reactor.

In addition to the normal reactivity considerations which are thereby involved, it is essential to make an assessment of possible loss in reactivity suppression which could be incurred by equipment failure, or indeed during normal maintenance. Certainly it is preferable that no changes whatsoever be made to the safety and control system without a suitable reserve of potential negative reactivity being held available. This can generally be achieved by a suitable splitting of control absorbers into discrete banks.

It is an additional advantage if the reactor can be supplied with at least two independent and dissimilar shut-down mechanisms, whether these are both in the form of absorber elements, or, as in water systems, one is achieved by moderator dumping. This provides an added safeguard against systematic failures which might invalidate even a multiplicity of similar mechanisms, as could result for example, from a common maintenance error.



Recorded self-stabilizing transients of Bepo, diverging with step values of 2×10^{-3} and $1 \times 10^{-3}\delta$ k/k, upper and lower curves respectively. Initially the reactor was operating at 100 kW with full coolant flow. The resulting variation in reactor power is determined by the thermal lags in the system combined with the fuel and moderator temperature coefficients of reactivity. Final power level at which the reactor stabilizes is dependent on the sustained rate of cooling (Fig. 1)

Control instrumentation and mechanisms

(i) A knowledge of all those physical properties relevant to the safety of the system must be available at all times to the operator. These include such quantities as flux, temperature, pressure, flow-rates, activity levels, etc.

This is no less important in the shut-down condition and particularly during start-up operation. It is essential to guarantee the provision of a sufficient natural or artificial source of neutrons, often in conjunction with pulse-counting equipment, to evaluate precisely the approach to criticality.

(ii) All safety mechanisms should be gravity-assisted in action and only highly reliable components should be used in control circuits.

(iii) The control and safety systems should incorporate a failure-to-safety characteristic in all important functions. There are three main stages in the control sequence, first the flux-sensing device, with its associated amplification, secondly the guard line and thirdly the absorber mechanism. A complete failure of any of these stages should automatically cause the reactor to be put into an inherently safe condition, by causing the insertion of the control absorbers. Lesser failures can reasonably be indicated by visual and audible warnings to the operator who may be able to take appropriate remedial action without incurring unnecessary shut-downs.

(iv) The control system should incorporate simple and reliable monitoring and test circuits to ensure the correct operation of component parts of the system.

(v) The main trip functions should employ a suitable multiplicity of parallel signal channels, see Fig. 2, preferably with a coincidence system, i.e. one in which trip signals are required from two or more channels simultaneously to promote a shut-down. This has the advantage of reducing spurious shut-downs by instrument failure and allows the testing of individual channels or trips during operation without shutting down the reactor.

(vi) All instruments and mechanisms should be accessible for testing and maintenance on a regular routine basis, either in the operating or in the shut-down condition as appropriate. In this connexion Lewis (5) has suggested that maintenance operations to more than one instrument, especially in the case of control instruments, should be carried out only when the reactor is operating.

Guaranteed supplies and operational requirements

A fail-safe characteristic in the safety system will ensure that an interruption of electrical power to the reactor will cause it to be shut down by the gravity-assisted mechanisms.

This may not, however, be sufficient to guarantee the safety of the system if the necessary cooling to dissipate the residual fission-product heating cannot be maintained by natural processes alone. In such circumstances provision must be made of guaranteed secondary power and coolant supplies sufficient to prevent overheating of the core.

All operations, including the handling of irradiated fuel, must as far as possible be predetermined and the design conditioned accordingly.

Interlock facilities, as other mechanisms, should be tested and maintained on a regular routine basis, though these are not strictly primary safety devices. The first line of defence lies in adherence to correctly specified operator action,

backed up by interlocking devices. There is a special need to be certain that interlocking devices cannot, under any foreseeable conditions, lock the operator in a hazardous situation.

HIGH FLUX RESEARCH REACTORS (10—20 MWt)

Certain safety problems are accentuated as operating flux levels increase. This is particularly true in the high-flux irradiation facilities which are designed to supply the highest possible neutron flux to as many varied experimental facilities as possible. Here there is the additional complication that the experiments can contribute significantly to the reactivity of the system, and can themselves prejudice the integrity of the reactor containment, whilst gamma heating in the experimental and reactor components will be high.

High flux levels (e.g. peak values $\sim 1{\cdot}4 \times 10^{14}$ thermal n/cm² s as in the AERE Harwell reactors Dido and Pluto) require a highly enriched fuel with a high fuel-metal ratio, and xenon and samarium build up will be such that the initial excess reactivity investment must be large to attain a useful utilization cycle. The control system must cope with this large excess reactivity without however, producing undue flux distortion.

In addition to the general principles already enumerated, the high flux reactor requires that stipulated rates of reactivity addition be related to the thermal stresses generated by rapid power changes (a factor which is very important in power reactors). Furthermore, allowance must be made for the physical and chemical changes resulting from high neutron and gamma radiation doses.

A discipline to control the insertion of experimental equipment in the reactor must be properly exercised, and here too certain well-proven general principles have evolved from experience on such systems, including the following:

(i) Each experiment should be subject to a formal safety analysis to ensure that the equipment cannot damage the reactor.

(ii) Preliminary thermal and hydraulic component tests and, where possible, experimental reactivity measurements should be made before the equipment is inserted in the reactor.

(iii) Experiments should be as self-contained as possible and fully instrumented, i.e. where necessary they should have their own safety circuits, cooling and containment.

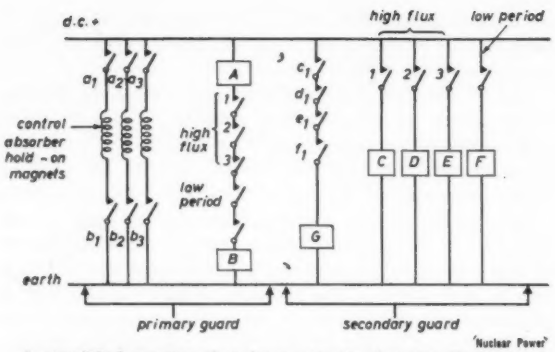
(iv) Any experiment which can produce large reactivity changes during an operating cycle should be equipped with separate control, and no experimental equipment should in any case reverse any inherent negative reactivity coefficients in the system.

In a reactor of this type the resulting complexity of controls from a number of experiments in the reactor at one time can cause a significant increase in spurious shut-downs from equipment failures. A very high premium is, therefore, placed upon the use of these modes of reactor shut-down which incur the shortest possible start-up delay when the fault has been cleared.

SAFETY ASSESSMENT

It is now accepted practice to subject a new reactor, before commissioning, to an impartial, systematic safety analysis by an independent group with collective experience over the whole range of reactor technology. In most cases they will base their study upon a formal safety assessment document written jointly by the design and operational staff.

It is at this level, as well as among a more general public, that there is a need for realistic thinking on safety philosophy. A more balanced view must gradually be evolved than the ultra-cautious one which may at present be required by ' political necessity '. Ultimately, on the basis of satisfactory operational experience, nuclear reactors will be absorbed into the catalogue of ' conventional ' machinery. This implies



'Nuclear Power'

A simplified reactor shut-down circuit, showing duplication of safety circuits and high flux trips. The safety circuits provide alternative methods for a detector to shut down the reactor via relays (A, B, C, D, etc.) and their contacts (a, b, c, d, etc.). By using duplicate contacts on relays C, D, E, F, visible and audible fault indicators can be provided. Two-out-of-three operation of the control mechanism from the high flux channels can be achieved by paralleling relay contacts in the safety lines (Fig. 2)

that a balance will have been established between acceptable risk and economic cost.

A range of personal judgement may exist as to what is an acceptable risk on a research reactor, when balancing safety, cost and operational convenience. A major release of radiotoxic materials must clearly be precluded, but the balance may be on somewhat arbitrary grounds when considering those contingencies in which damage is limited to the reactor itself. Reactor safety assessors must fully protect the interests of those who live or work around the system; thereafter their primary function is to ensure that the risks accepted by the operators have been properly calculated.

It is rarely possible to give absolute guarantees that the preventive measures designed into a reactor can never fail. As we have said already, the primary safeguard must lie in the development and conscientious application of safe operating procedures. This naturally requires that reactor operation be entrusted only to responsible and experienced professional staff, when the automatic mechanical protective devices become a second line of defence backing up the operator. It is then unnecessary to base a safety evaluation on the assumption that the system must be proof against every conceivable combination of operating error. What is necessary is to show that unsafe conditions do not arise from any single failure, or consequential series of failures of operating procedures or equipment, and that all reasonable steps have been taken to eliminate such unsafe conditions. This latter will include a study of potential fault conditions and the proving of equipment. Sufficient attention must be given to maintenance and loading operations on the reactor when it is nominally in a non-operational state.

The safety analysis must contain a prediction of the transient kinetic behaviour of the reactor, using the best available values of such parameters as mean neutron lifetime, temperature and void coefficients, control system response times, etc. The main requirement is to predict the behaviour of the system in response to the maximum spontaneous reactivity gain which can accidentally occur on it. This will help to define the shut-down functions upon which reliance will have to be placed in a given circumstance. Also it will permit the specification of the maximum permissible rate of reactivity addition which may be invested in the control system during reactor start-up. It is obvious that this specification, and other safety features with design implications, cannot be derived

merely by reference to the steady state design parameters which will apply in normal operation. When the necessary transient parameters are not known with accuracy, estimates must be used which are weighted to err in favour of increased stringency in the resultant safety specifications.

The safety evaluation of the reactor should include, in principle at least, consideration of all conceivable accidents, irrespective of their improbability. A definition may then be made of the 'worst accident', i.e. that accident, regardless of its improbability, which has the most hazardous consequences. Similarly the 'worst credible accident' may be defined. This is the most hazardous of that class of accidents which are considered to have a sufficient probability to prevent their occurrence being entirely discounted during the lifetime of the reactor. Invariably the definition of a 'credible accident' ultimately derives from an exercise of judgement, and as such is never divorced from the consequences which ensue from it. The system must finally contain sufficient safeguards to ensure that the residual credible class of accident includes none with totally unacceptable consequences.

In tracing the course of an accident condition it is necessary to evaluate the number of faults, human or mechanical, which must exist simultaneously to endanger the system. It is then necessary to establish which of these are consequential and which are truly independent. Certainly the more independent failures which are required, the safer the system may be construed to be, but here is a point at which a realistic approach must be made. The simultaneous occurrence of two truly independent states each of low order probability is of a corresponding second order probability. It is seldom possible to put an exact figure on such quantities, but let further consideration of second order probabilities be restricted at least to those failures which invalidate primary safeguards. The following example may illustrate the point.

On a liquid-moderated reactor a timing device was used to limit the operation of the main transfer pump to pumping periods of 15 sec., during which the pump delivered an amount of liquid which, if inadvertently added to a just-critical core, would not take the reactor prompt-critical. The installed timing device had operated successfully for a number of years, though certain potential faults existed in its design. Firstly it was not accurately calibrated down to 15 secs., being originally intended for use with much longer periods (0–30 mins.); secondly it was located in an accessible position which would allow unlawful changes to be made to the setting, and thirdly its action was not fail-safe, i.e. its failure would cause the transfer pump to go on operating as long as the operator kept his finger on the appropriate button. The question posed was what modifications, if any, should be made to this device and its associated circuit. Before considering the point it is necessary to examine it in the context of the overall safety philosophy of the reactor.

The reactor was controlled by moderator level, but was provisioned with two independent banks of safety rod absorbers which fell under gravity into guide tubes in the moderator. Much attention was given to the efficiency of this system, and it was found that it has always proved entirely reliable. Nevertheless subsequent safety arguments were always based on the pessimistic assumption that only one bank of rods would drop when required, and that the most reactive rod of this bank (of 4 rods) would also fail.

A partial dump level was specified, and a dump valve and line fitted at the appropriate height, at which the reactor loading (if in accordance with the lattice certificate) would be substantially sub-critical (at least 1·0%δk/k more than any spontaneous reactivity gain which could conceivably occur on the system in this condition). In practice the main transfer pump, and the associated timing device, was used to pump water to this partial dump level only. Thereafter a fine control pump was used, and the changeover was backed up by an interlock operating between the pump changeover and the partial dump valve. The fine control pump had no corresponding timing circuit, as the rate of the delivery was such that the associated rate of reactivity addition at criticality made this quite unnecessary. This interlock could be by-passed, but this was done only in exceptional circumstances for special reactor physics measurements on the reactor, which, in any case, involved very close supervision of operation of the pump.

Again, however, an additional safeguard was invoked. The transient calculations were consistently based on the assumption that the rate of reactivity addition by pumping was that of the main transfer pump, and this was set in consequence at a level which was of itself shown to be safe under credible conditions. Such conditions were taken as those in which any number of operating or mechanical faults could occur simultaneously to put the reactor in a potentially hazardous condition (e.g. embarked on a transient which self-stabilization alone would not safely contain), but that thereafter the operation of the high-level flux trips should actuate the stated proportion of the safety rods which would then, under all circumstances, safely shut-down the reactor. This ignored operation of the installed period trips, which could have been the quicker acting. The high-flux trips were installed as a one-out-of-three system, and set at a level consistent with the requirements indicated by the transient studies.

Only a serious breakdown in the operational control could really prejudice the safety of the system, and in this respect there were at least three independent and experienced levels safeguarding against this contingency, i.e. the reactor physicist, the reactor engineer and the reactor operator, each of whom had the separate right (and duty) to veto any operation outside the recognised safe procedures.

Reverting then, finally, to the timing mechanism. If it had been truly established that this was not a primary safety device, then here was a case in which expensive modification could be ruled unnecessary. The alternative view, however, is that any mechanism adjudged as necessary to safety should be properly designed and fail-safe in action. If the timing switch was not essential to safety, and did not contribute to operational convenience, its removal was to be preferred to the use of an inferior mechanism. This was a real situation; the reader is left to supply his own solution.

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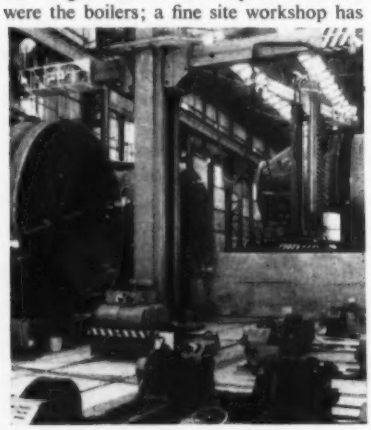
View of the Heavy Engineering Shop at Derby; the welding pit in the centre contains manipulating equipment for rotating vessels during seam welding and also provides a screened space for X-ray examination. The main X-ray and gamma ray booths are at the far end of the shop. In the foreground a strake is being prepared for insertion in the stress relieving furnace

Due to the size of the boilers and difficult site access an appreciable amount of the fabrication work is undertaken in the site workshop

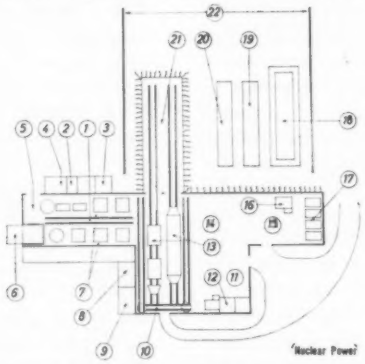
Boilers for Trawsfynydd

INTERNATIONAL COMBUSTION, who built the AGR heat exchangers, are manufacturing the 12 boilers for Trawsfynydd together with the associated pipework, headers, internals, etc. They are also making most of the primary circuit, the shield and pressure vessel cooling as well as various pressure vessel attachments. On a recent visit to the site and the Derby works *Nuclear Power* was shown the progress made in producing these. Naturally, the largest and most impressive items were the boilers; a fine site workshop has



In the foreground is one of the manipulators used at Trawsfynydd for pairing strakes together with boom welding equipment. After pairing the strakes are taken to the boiler assembly lines seen here in the background. The two parts of the shop are at different levels, this was found to be more economic because of difficult site contours

been built for welding sections from the works into finished boilers and for preparing other parts. The site, the only inland one in the UK, is difficult to get to and strakes are shipped to Portmadoc, about 12 miles away, and then brought to site on specially rebuilt roads. At site, the first lift was about four months late but production is now proceeding so smoothly that finished shells are being produced at the rate of one every four weeks rather than every seven weeks. Production is expected to be back on schedule by the sixth boiler. Strakes, 18 ft ½ in dia. and 9 ft 2½ in parallel length of max. plate thickness 2½ in, are received at the site workshop and welded into pairs using boom welding equipment and manipulating equipment. About 40 passes are needed to produce a

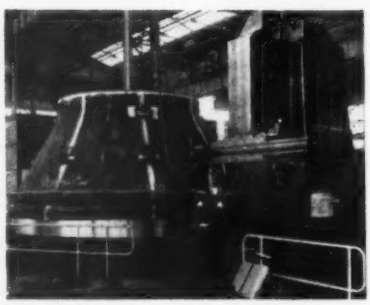


Layout of the site workshop at Trawsfynydd

1 Track for welding booms; 2 Admin. office; 3 Mess room; 4 Laboratory; 5 Unloading area; 6 X-ray pit; 7 Area for fabricating boiler sections; 8 Switch gear; 9 General stores; 10 Track for welding booms; 11 Casing cleaning building; 12 Covered store; 13 Boiler assembly lines; 14 Ducting fabrication shop; 15 Element shop; 16 Element drying house; 17 Element pickling and rinsing tanks; 18 Stress relieving furnace; 19 Hydraulic test plinth; 20 Cleaning and lifting area; 21 Workshop apron; 22 Goliath crane span

circumferential weld, depending on plate thickness.

The welded pairs are taken to boiler assembly lines by a 60-ton overhead crane. The finished boiler can then be moved out onto the apron under the Goliath which is used to lift the shell into the stress relieving furnace. The furnace is unusual in that oil combustion heaters are used and it is transportable for use on other sites. The temperature distribution is checked by 96 thermocouples to ensure that the shell is uniformly heated; the hot gases are distributed by means of ducts into the shell and then out through the manholes into the furnace. Latina is the only other station which uses a similar method of stress relieving.



The forged ring associated with a bottom cone assembly being machined in the Derby Works. This machine is also used to prepare the circumferential edges of the cone ends

After stress relieving, the shells are hydraulically tested at twice design pressure, the end domes and internal braces removed and the interior cleaned; the tube element supports are then bolted into place. The shell weighs about 350 tons at this time and represents nearly the maximum lift of the Goliath. The elements are fitted *in situ*, using a clean conditions house placed on top of the boiler. At the heavy engineering works at Derby (see picture at top of page), plates are flame cut, edge prepared on planers and then cold bent to semi-circular profile. Plates for the bottom and top domes are hot pressed to shape. They are then handwelded. Two halves for the parallel strakes are welded downhand using boom welding equipment similar to

A boiler shell in the stress relieving furnace before the roof has been placed in position

that at Trawsfynydd and the longitudinal seams radiographed. Holes for the thermal sleeves are burnt and the sleeves welded in. After crack detection on the shell fillet weld the strake is stress relieved in a towns' gas fired furnace. Two of the boilers will be fabricated from electric furnace C-Mn steel to provide information on its behaviour under operating conditions. The others are in low-carbon silicon killed boiler steel. Other parts for Trawsfynydd including headers designed for inspection by intrascope, tube element banks, and standpipes and thermocouple ducts are also in an advanced state at the Works. The work for the boilers is backed up by extensive non-destructive testing services, a welding school and laboratory and a rig where tests on the heat exchange properties of different types of finned tubes are carried out.

Semiconductor radiation detectors, transistor circuits and the design and use of analysers and data-handling equipment were featured at

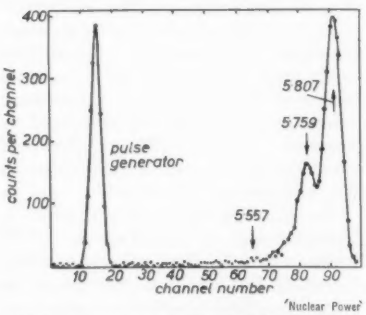
The Belgrade Convention on Nuclear Electronics

by DENIS TAYLOR, M.Sc., Ph.D., M.I.E.E., Plessey Nucleonics Ltd.

THIS IAEA CONVENTION was the largest and probably the most successful conference on nuclear electronics yet held. Some of the more interesting papers are described below.

In the Scintillation Counter Session, J. Birks (UK) presented a paper on 'Improved Organic Scintillator Detectors', in which he derived equations for the practical scintillation efficiency (photoelectrons/MeV) of organic crystals and solutions in terms of molecular parameters and applied them to typical scintillation counter systems. His results suggest several improvements, e.g., the use of binary rather than ternary solutions, the use of quartz rather than glass windows and the reconsideration of mixed crystal scintillators based on naphthalene. Improvements by a factor of two in the figure of merit are possible.

There were a number of papers on the Cerenkov effect and one which attracted attention was 'Detection of the Cerenkov Effect of Beta Particles in a Liquid by Fast Photomultipliers in Coincidence' by R. Ducros and G. Ducros (France). Two photomultipliers are employed viewing the same source of light, an arrangement which eliminates the cooling normally required, and permits a significant reduction in volume and weight of the apparatus used. The coincidence circuit has a coincidence time of 5×10^{-9}s for the purpose of eliminating extraneous counts, and the apparatus has been used for the measurement of the Sr−Y activity in water, in concentrations at the m.p.l.



Alpha spectrum for Cm-244 25mm² Au-Si counter, 300 ohm-cm 100 V. The measurement was made four months after manufacture and the performance improved gradually over this period. No method has been found of accelerating this aging process (Fig. 1)

At the International Atomic Energy Agency Nuclear Electronics conference at Belgrade from May 15 to 20, 1961 about 150 papers were presented and over 30 countries represented. A small scientific exhibition was associated with the conference, but only countries near Yugoslavia took part, major exhibits coming from Austria, Czechoslovakia, Israel, Italy, Poland, Rumania and Yugoslavia. Little new was exhibited but it was interesting to see the progress made in nuclear electronics by countries in this area

K. Takumi and S. Yamada (Japan) also dealt with a similar subject. They were studying the possible application of Cerenkov detection for the detection of burst fuel element cans. They reported on the use of a detection volume of 15 l in temperature-controlled enclosures for continuous monitoring and achieved a detection sensitivity of about 3×10^{-7} microcurie/ml (i.e about 1/10 m.p.l. for Sr-90).

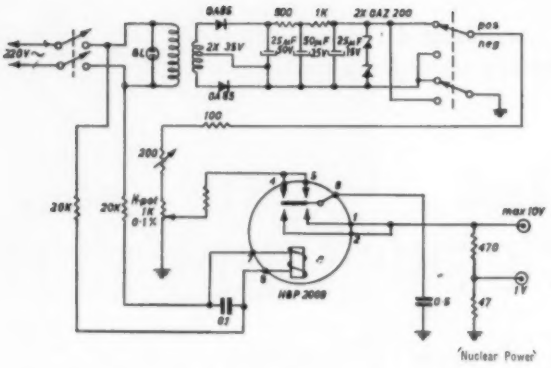
SEMICONDUCTOR DEVICES

Much of the convention was devoted to semiconductor devices and their application in detection. There were important contributions from Oak Ridge (USA), Nobel Institute (Stockholm) and Harwell. Surface barrier detectors received a great deal of attention and there was much discussion on constructional techniques.

The following method* is typical: the material used is *n*-type silicon with a resistivity of 300 ohm-cm and higher. After cutting with a diamond saw to the proper size, the detector elements are treated as follows:

1. Lapping with successively finer powder of Al_2O_3 or SiC down to 800 mesh. Very careful cleaning in water between successive steps in this process.
2. Careful cleaning in distilled water and boiling for five minutes in conc. nitric acid.
3. Etching at 0°C for two minutes in modified CP-4 (2 volumes HNO_3, 1 volume HF, 1 volume H Ac all conc.). After this the element is transferred to a new bath of the same composition and is etched for another three minutes. The etching and the following cleaning are carried out in a well ventilated dry box.
4. Cleaning by successive dilution of the acid with de-ionized water or boiled distilled water. Air must not be admitted to the surface as long as acid is present. Extended cleaning in distilled water.
5. Evaporation of 100 micrograms/cm² of gold on to the front surface. Before evaporation the gold is cleaned in conc. HCl.
6. After this the elements are stored in dry air at room temperature for 3–5 days.
7. Additional gold is evaporated on to a limited area of the gold surface. Here the electrical connexion is then made via 0·1 mm Cu wire fastened with JMC Thermo-setting Silver Cement FSP 49.

* See paper by B. Åström, N. G. E. Johansson and G. Wickenberg (Sweden) or paper by G. Dearnaley, A. T. G. Ferguson, A. B. Whitehead and J. H. Montague (UK) for more details.



Mercury relay pulse generator used for semiconductor radiation tests (Fig. 2)

Figure 1 is an example of the alpha spectra measured with one of the 25 mm² detectors as reported by Åström. A pulse generator is a very necessary adjunct in this work. Figure 2 gives the circuit of an inexpensive pulse generator reported at the Convention. Figure 3 is the spectrum of alpha-particles from Am-241 measured with a silicon surface barrier detector reported by the Harwell team. It can be seen that the four alpha groups are clearly resolved. The width of half maximum is 16 keV or 0·30% of the pulse height.

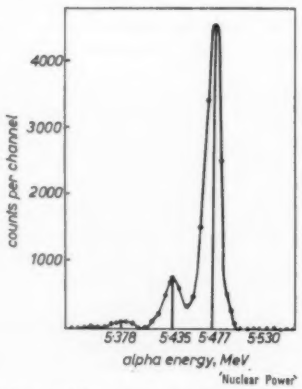
A recent application of the surface barrier detector reported was its use in a proton-recoil neutron spectrometer. The radiator is a thin layer of hydrogenous material either evaporated on to the detector surface, or in the form of a self supporting film mounted just above the counter face. The authors (G. Dearnaley *et al.*) showed how a compensated system could be used (Fig. 4) to balance out the background from neutron interactions with the silicon.

One of the most interesting papers was by J. W. Mayer, N. A. Baily and H. L. Dunlap (USA) entitled ' Characteristics of Ion Drifted *p-i-n* Junction Particle Detectors '. They explained that *p-n* junctions made of silicon using shallow phosphorus diffused junctions have been suitable for the detection of heavy charged particles, but not for beta or gamma-radiation. To make silicon junctions suitable it was necessary to increase the energy deposited within the charge sensitive region. This could evidently be done by increasing the atomic number of the semiconductor material, or by increasing the depth of the charge sensitive regions. Mayer and his collaborators indicated how they had succeeded with the latter approach. Silicon had been successively diffused with a lithium impurity and by ion-drift techniques a sensitive volume had been established with a width of 5 mm in comparison with the usual 10 to 100 micron width established when silicon is diffused with phosphorus. Units have, in fact, been fabricated from float-zoned and pulled material (1 to 30 ohm-cm) with active areas of 1 to 6 cm² with drifted regions up to 5 mm in depth. The response of a 2 mm deep *p-i-n* junction detector to 662 keV monoenergetic gamma rays of the Cs-137 decay products is shown in Fig. 5.

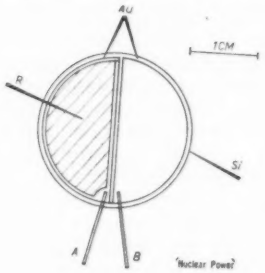
There were also papers on solid state detectors for the measurement of dE/dx and total energy in nuclear reactions. Comparisons between the semiconductor and gas ion chamber dE/dx detectors showed that the energy resolution of the semiconductor detector was improved over the gas ion-chamber in accordance with the ionization efficiency of the stopping media. H. E. Wegner (USA) reported that an experimental lithium diffused *p-n* junction with a 2 mm space charge region detected 15 MeV protons, 17 MeV deuterons and 15 MeV tritons with about 1% energy resolution and excellent mass separation.

ELECTRONIC CIRCUITS

Separate sessions were devoted to 1. Multi-channel Analysers and Data Handling, 2. Classical Electronics, and 3. Fast Electronics. It has been reported that the scintillation pulse shape which is characteristic of the exciting particle (e.g. electron, proton, alpha-particle, etc.), can be converted into a pulse height parameter. This allows a method of displaying, using a multi-channel analyser, the components of a mixed particle beam exciting the scintillator. Several papers dealt with electronic methods for the discrimination of scintillation pulse shape in this way. E. Gatti and F. de Martini (Italy) reported on a study of the general problem of different shape signal discrimination by means of linear networks and developed a theory to synthesize an ' optimum ' linear filter to discriminate between different specific ionizing power, low energy, elementary particles detected by a scintillation counter. They described a circuit embodying such a filter used for discriminating between Po-210 alpha-particles and Cs-137 gamma rays (Compton electrons) using an anthracene scintillation counter. M. Forte, A. Korsta and C. Maranzana (Italy) also reported on a number of electronic techniques which they have used in connexion with this type of discrimination (Fig. 6).



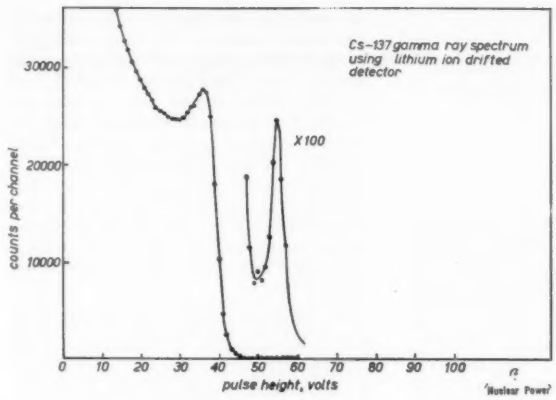
Alpha-particle spectrum from Am–241 observed with silicon surface-barrier detector (Fig. 3)



Schematic diagram of a neutron spectrometer. The two semi-circular areas marked Au are gold-covered sensitive areas of the two counters. R is the hydrogenous radiator, a plastic film which is suspended over the left-hand counter. A and B are the signal leads of the two counters (Fig. 4)

L. J. de Vries and F. Udo (Holland) also spoke on Pulse Shape Discrimination. They indicated that a neutron monitor based on linear pulse form discrimination could be employed to measure down to 10% of the m.p. neutron dose in the presence of a gamma flux of four times the m.p.l.

On Data Handling Equipment, A. Roberts and C. Rockwood (USA) spoke on ' A New Counter Data Handling Facility ', and described the system they had designed and produced to analyse and store complex electronic counter data from high energy pulsed accelerators. F. A. Kirsten and D. A. Mack (USA) presented a paper, ' Instrumentation of Multi-channel Counter



Cs–137 Gamma Spectrum using a lithium ion drifted detector. It can be seen that the predominant mechanism contributing to the observed pulse weight distribution is Compton electrons (Fig. 5)

Experiments '. Potentially useful nuclear events were first selected by the fast (10^{-8} s) logic part of the system. Circuits performing simple logical functions were packaged in modular form for easy grouping into particular coincidence, gating and mixed configurations. Circuits with slower response time (10^{-6} s and less) were used to perform temporary storage and recording operations. Automatic test routines were used to align initially the equipment as well as to provide continuous calibrations during the experiments.

There were a number of reports on fast counting circuits (e.g. R. Sugarman, W. A. Higinbotham and A. H. Yonda '100 Megacycle Counting System' and J. Duchemin and J. Mey 'Amplitude Discriminator and Scaler with a resolving time of 5 nanosec'), as well as papers on tunnel diodes and their applications in a variety of circuits (e.g. Verroust 'Use of Tunnel Diodes in fast Electronics in connexion with discrimination and counting devices in Nuclear Physics').

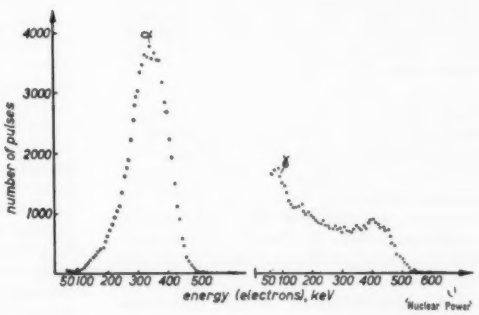
INSTRUMENTS

C. J. Borkowski and R. H. Dilworth (USA), in a paper entitled 'A Personal Radiation Monitor', described an instrument* which weighs 3½ oz and is the size of a fountain pen. Worn in the pocket, the device provides immediate and visual indication of the gamma dose rate over a range from background to 200 r/h. The flashing rate of a neon lamp and the pitch of an audible warning tone increases in proportion to dose rate. In its normal mode of use, the alarm tone pitch reaches a limit of 2800 c/s at about 2 r/h. If required the instrument can be inverted and a 100 times decrease in sensitivity be effected by a mercury altitude switch. In its inverted mode the limit proportional indication is 200 r/h. There is no on-off switch and in the latest form of apparatus, the battery life is one year.

* Application to manufacture these instruments in the UK has been made by Plessey Nucleonics Limited.

D. M. Papke (USA) presented a paper entitled, 'A Dose Sensitive Radiation Alarm Instrument with Rate Compensation'. Here the approach was to evolve a design which discriminated according to the dose rate so that it integrated in the normal way for a certain range of dose rates, but for dose rates less than a certain pre-set limit cancellation was provided. Such an alarm operating on the integrated dose offers many advantages over the conventional ones for the detection of accidental critical reactor reactions.

A. Blanc and J. Lequais (France) in 'Apparatus for Recording Iodine-131 Activity', described a device for recording the activity in the air and giving an alarm when the activity reached a predetermined value or underwent an abnormally rapid change. The air is aspired (at 20 m³/h) across a specially-shaped tube of activated charcoal surrounding a crystal scintillator. The iodine thus permanently accumulates at a short distance (a few mm) from the detector. The activity is counted selectively in an energy band centralized on 0·364 MeV, but shielding of the detector system with lead is provided to reduce background. The apparatus integrates with a time constant of 8 days. A small accidental leak producing in air 1 m.p.l. is detected in about ½ h and the time necessary for such leaks is inversely proportional to the concentration.



Po–210 alpha particles and Cs–137 γ spectra in anthracene discrimination by linear filter; the scintillation efficiency is reduced (Fig. 6)

N. T. Clarke (UK) dealt with various aspects of plutonium monitoring. He pointed out that most of the Pu-239 particles are larger than 0·05 micron and the natural dust particles 0·04 micron, and it was therefore reasonable to use the impactor technique in an air monitor for the detection of particulate plutonium. In fact the impactor discriminates in favour of the heavy plutonium by a factor of 10 to 1. On the other hand, W. O. Gentry and G. B. Seaborn (USA) in their paper on air monitoring, mentioned that in monitoring uranium at the Separation Plant at Oak Ridge, the size of the dust particles formed during a uranium hexafluoride release vary and approach the size of dust. An instrument based on the impaction method of collection is not helpful in this case, and the dust from a suitable sample is continuously entrapped on a filter paper disc. A quasi-equilibrium condition occurs in which the rate of arrival of new radioactivity is equal to the decay rate of the material previously collected. This equilibrium radioactivity level will vary slowly as the natural background activity varies. The instrument is adjusted so that the maximum rate on natural background is slightly below the threshold of alarm, then any release above the rate of rise of background will cause the alarm to operate. The maximum rate of rise of background at Oak Ridge was about 40 disintegrations/min per min, and this was chosen as the minimum alarm rate setting.

The final paper, 'Control of Radiation through Normal Phone Lines' was from the Boris Kidric Institute in Belgrade and was presented by B. J. Kovac, S. D. Muzdeka and M. V. Sobajic. It described a logarithmic counting-rate radiation monitor which could be connected to a normal telephone apparatus and would provide information on the radiation level at the area in question as an answer to the phone call, without involving the presence of a person at the monitor end.

Note: All the papers and a detailed account of the discussion will be published within the next six to nine months.

Points from Papers

reports, meetings, conferences

VBWR FUEL ASSEMBLIES

The design of 24 fuel assemblies for high power density operation in the Vallecitos Boiling Water Reactor is described. The assemblies use UO_2 fuel and are 304 stainless steel clad; current oxide fuel fabrication processes are used. They will be used to evaluate and study partial core operation in the VBWR. The average power density will be 90 kW/l and average exposure 10,000 MWd/tonne. Two instrumented assemblies will measure temperature, flow, pressure and neutron flux characteristics. The programme is part of the AEC sponsored High Power Density research and development project in support of the 50 MW BWR to be built at Big Rock Point by the Consumers Power Company.

Design and fabrication of high power density fuel assemblies for VBWR irradiation testing. W. D. Fowler and J. W. Lingafelter. General Electric, Atomic Power Equipment Department. **Report GEAP 3609.** 75 pp. For copies apply to *Nuclear Power*.

THERMOCOUPLES

Tests on platinum/platinum-10% rhodium thermocouples heated electrically to 2500°F and subjected to a maximum integrated flux of 6×10^{19}n/cm²s fast neutrons and $1{\cdot}6\times10^{20}$n/cm²s thermal neutrons have shown a de-calibration effect of about 8%. Insulation (alumina) resistance measurements carried out at the same time gave essentially constant values.

Operations of thermocouples under conditions of high temperature and nuclear radiation. G. F. Levy, R. R. Fouse and R. Sherwin. The Marquardt Corporation. 19 pp. For copies apply to *Nuclear Power*.

Experience is described of platinum/platinum–10% rhodium thermocouples insulated with magnesia and sheathed in commercial platinum. These thermocouples performed well up to 2400°F and magnesia was found to be a suitable insulator up to 2900°F. There is information, however, that it depreciates rapidly with increasing temperature. Future work will include the testing of beryllia and thoria as insulators.

Some experiences with noble-metal metal-sheathed thermocouples. W. E. Bostwick, University of California, Lawrence Radiation Laboratory. **Report UCRL-6325.** 27 pp. Copies available from *Nuclear Power*.

WASTE HANDLING

Between 65 to 70 million gallons of high-level wastes are now in storage in the USA at three sites: Hanford, Savannah River Plant and the National Reactor Testing Station, Idaho. An enormous amount of radioactivity is contained in these wastes and will increase as more reactors are commissioned. This paper reports on the research and development programme dealing with the ultimate disposal of these materials. The two general approaches followed are (1) conversion in solid oxide form or fixation in an inert, non-leachable solid carrier, (2) direct disposal into specific geological formations.

Several methods following the first approach are being studied. These include use of fluidized beds, pot calcination, radiant-heated spray columns and rotary kilns.

Recent developments in the processing and ultimate disposal of high-level radioactive wastes. W. G. Belter. USAEC. Paper presented at the 16th Annual Purdue Industrial Waste Conference. 30 pp. Copies available from *Nuclear Power*.

COMPETITIVE MAGNOX—HPR

An estimated cost of £160/kW for this 60 MW reactor is claimed. This would make it competitive with enriched fuel reactors, even in high capital charge regions. The design uses a concrete pressure vessel, a comparatively small core (65 tonnes of nat. U, 750 tons of graphite), and a high operating gas pressure (540 lbf/in²g).

HPR—a 60 MW natural uranium nuclear power station. R. E. Strickland and T. J. Fowler. *The Journal of The British Nuclear Energy Conference*, April, 1961.

HIGH-SPEED REACTOR CONTROL

This report describes a novel concept of reactor control of continually driving the reactor towards its equilibrium state as rapidly as possible from perturbed states. These arise from the more turbulent and effusive boiling that ensues when the power density of BWR's is increased. A controller computer which instantaneously senses the perturbed states (neutron density and period) of the reactor computes, in real time, the reactivity policy which then sends actuating signals to the 'rod' system. The control problem is formulated in a way analogous to the brachistochrone class of problems instead of the small excursion linearized theory. The reactivity policy is then derived, using dynamic programming, from an equation giving the minimum time for the reactor to be 'slammed' back to equilibrium. This policy, which depends on the perturbed state co-ordinates, is then used in the controller computer in the form of a wired program.

Bang bang reactor control. M. Ash. System Development Corporation. **Report SP-262.** 18 pp. Copies available from *Nuclear Power*.

FISSION PRODUCT TRAPS

A report on the fission product trapping capabilities of various charcoals and metal-charcoal combinations outlines the attempt to develop a satisfactory trap for use in gas-cooled reactors. The trap is designed to be located within each fuel element and volatile fission products are removed from a purge stream passed over the element. In this way the products cannot plate out in the primary coolant system before reaching a trap. Trapping efficiency is increased as the fission products are in a relatively concentrated form. The apparatus described has been used to test the iodine and tellurium trapping capabilities of silver and copper coated charcoal at temperatures up to 900°F.

High temperature fission product trap study for gas-cooled reactors. R. M. Watkins, D. D. Busch and L. R. Zumwalt. General Atomic. **Report GA-1990.** 20 pp. Preprint of paper presented to ANS meeting June, 1961. Copies available from *Nuclear Power*.

NUCLEATE BOILING WORK

Using a special thermocouple designed to measure the temperature of a small area and having an extremely rapid response time, the authors say the surface temperature was found to drop occasionally 20-30°F in about 2 milliseconds during the boiling of water. The significance of this rapid extraction of heat during a short time interval is that it provides a new clue to the understanding of nucleate boiling. A hypothesis is advanced to explain the observations.

The measurement of rapid surface temperature fluctuations during nucleate boiling of water. F. D. Moore and R. B. Mesler. University of Kansas, Center for Research in Engineering Science. 21 pp. Copies available from *Nuclear Power*.

New Reports

Power distribution studies in the critical experiment for the heat transfer experiment-III. H. L. Bermanis. General Electric, Aircraft Nuclear Propulsion Department. 13 pp. Copies available from *Nuclear Power*.

Nuclear heating measurements in the heat transfer reactor experiment-III. C. I. McVey. General Electric, Aircraft Nuclear Propulsion Department. 10 pp. Copies available from *Nuclear Power*.

Lectures on criticality. E. D. Pendlebury, E. R. Woodcock, A. F. Thomas, K. D. B. Johnson and C. M. Nicholls. UKAEA Risley. **Report AHSB (S) R4.** 96 pp. Available from HMSO 9*s*.

Heating of liquid hydrogen from nuclear radiation. W. G. Thompson and C. G. Johnson. Convair Astronautics. 19 pp. Copies available from *Nuclear Power*.

Proceedings of the symposium on non-destructive testing trends in the AEC reactor program. USAEC. **Report TID-7600.** 86 pp. Available from OTS $2.00 or depository library.

In-pile fission gas release behaviour of alumina coated UO_2 particles. G. E. Raines *et al.* Battelle Memorial Institute. Paper presented to ANS meeting June, 1961. Copies of a 600-word summary available from *Nuclear Power*.

'Nuclear Power' INFORMATION

The papers reviewed here represent only a very small selection of those acquired and read by *Nuclear Power*. If you hear of a paper and have difficulty in obtaining a copy, write or telephone *Nuclear Power* Information Bureau, 77-79 Charlotte Street, London W1, MUSeum 8252.

Fourth symposium on temperature

A selection of papers presented at the symposium held at Columbus, Ohio, in March, are reviewed below

HIGH TEMPERATURES

When speaking about the temperature of plasmas, shock waves or arcs, what is meant is the electron excitation parameter in the Boltzmann distribution and/or the Saha equation. When the intensity of a spectrum line is considered there is in the equation an emission f-value which is a constant of the electronic transition and is also known as the oscillator strength or the number of dispersion electrons. The difficulty in attempting temperature measurements based on this method is the lack of data on oscillator strengths. This report examines methods and errors in f-value determinations and calculations and reviews the available literature.

Availability of atomic oscillator strengths for application to studies of high-temperature plasmas and atomic structure. R. Hefferlin. Southern Missionary College. Paper C8 of the Fourth Symposium on Temperature, Its Measurement and Control in Science and Industry. Copies available from *Nuclear Power*.

PLATINUM THERMOELEMENTS

A new patented method of producing platinum for thermocouple elements is described by the author. The material, known as 'Fibro' platinum has a higher strength than normal platinum and is recommended for use in thermocouples which may be subjected to abnormal handling or abnormal stresses. The paper includes a description of the fabrication process and gives graphs of the hot tensile strength and stress-to-rupture life compared with normally processed platinum.

Fibro platinum for thermocouple elements. J. S. Hill. Engelhard Industries Inc. 10 pp. Copies available from *Nuclear Power*.

FUEL ELEMENT TEMPERATURES

To measure the surface temperature of nuclear fuel elements accurately the thermocouples used must be mechanically reliable and the effect of coolant on them must be small and predictable. This paper reports on a method of fabrication of attached thermocouples where both these requirements are met. The paper also includes charts showing the theoretical dependence of the cooling correction upon such factors as Reynolds number, length of lead wire and temperature. The cooling corrections for air were experimentally measured and correlated by using a theoretical analysis of heat transfer within the thermocouple.

Thermocouples for measurement of the surface temperature of nuclear fuel elements. W. E. Browning, Jr. and H. L. Hemphill. Oak Ridge National Laboratory. 34 pp. Copies available from *Nuclear Power*.

RADIATION EFFECTS

No gross effects have been observed of thermocouple outputs when operating in nuclear reactors of medium flux. At levels of the order of above 10^{14} n/cm²s, however, transmutation and nuclear alloying can become significant. There are also limitations on the type of insulation that may be used. This paper reports work done on this problem on Chromel-Alumel and platinum/platinum-10% rhodium. The results indicate that the most desirable metals from the nuclear alloying standpoint are molybdenum, platinum and tungsten. Other metals, not commonly used, which have desirable properties, are osmium, ruthenium and niobium. The report concludes that research is required to find new thermocouple materials which will have satisfactory thermoelectric output, good chemical and mechanical stability at high temperatures, and low neutron capture cross-sections.

The effects of nuclear radiation on thermocouples. M. J. Kelly, W. W. Johnston and C. D. Bauman. Oak Ridge National Laboratory. 16 pp. Copies available from *Nuclear Power*.

This paper reports a computer program devised to simulate the effect of a twenty-year irradiation in a thermal neutron flux of 10^{14} n/cm²s on six common thermocouples. The results show that thermocouples composed of copper, rhodium, tungsten and rhenium undergo significant composition changes while Chromel-Alumel thermocouples appear to be unchanged. The paper discusses the nuclear processes involved in the composition changes, gives details of the computer program and also discusses the relative positions of thermal and neutron gradients which affect thermocouple calibration.

Calculated radiation induced changes in thermocouple composition. W. E. Browning, Jr. and C. E. Miller, Jr. Oak Ridge National Laboratory. 25 pp. Copies available from *Nuclear Power*.

EFFECT OF COLD WORKING

Most of the work reported on the effects of cold working and annealing on thermoelectric properties has been on relatively pure metals and dilute solid solutions. The present study is concerned with the effect of cold drawing on the thermal emf of seven common thermoelements. The authors report that there is no evidence of any rapid recovery phenomena immediately following cold work and that stress relief occurs slowly with time at room temperature. Depending on the material, recovery occurs between 300 and 500° C for a stress equivalent of 20% reduction of area.

The effect of cold working upon thermoelements. D. D. Pollock and D. I. Finch. Leeds and Northrup Co. 17 pp. Copies available from *Nuclear Power*.

EMF INSTABILITY

The report listed is mainly concerned with the use of tungsten as an emf reference. This is because measurement using Pt 27 is not possible for refractory metals where heat treatment or measurement is required at temperatures above the nominal limits of platinum, 3000°F. At these high temperatures it is important to separate emf instability and temperature measurement problems, and a technique has been developed to test emf stability with the use of a referee. This referee is a thermocouple wire which can be joined to or removed from a permanent junction. In this way it goes through a minimum of heat treatment and thermal cycling. The report states that no instability has been observed in stress relieved commercial tungsten below 3600°F. Most commercial tungsten is emf stable to 4000°F and some stable to 4500°F. Selected commercial tungsten can, therefore, be considered as an emf reference material for temperatures above 3000°F.

The measurement of high temperature emf characteristics I emf instability. F. W. Kuether. Honeywell. 13pp. Copies available from *Nuclear Power*.

EMF SCATTER

The authors describe a thermocouple property which has been observed at all temperatures and has been reported under such subject headings as homogeneity, inhomogeneity and uniqueness. Their preferred term is 'emf scatter' and they examine materials which are free of emf instability (see above). The material examined for this study of emf scatter as a function of temperature was tungsten supplied by three leading manufacturers, General Electric, North American Philips and Sylvania. They report that the inter-lot scatter of GE and Sylvania tungsten was substantially the same; not enough data was available to comment on the NAP tungsten. They say that the long range and especially medium range emf scatter of commercial tungsten is widely variable. On the other hand the unusually small medium range scatter of some commercial tungsten makes it attractive as a high temperature reference. This small scatter suggests that the powder metallurgy and the metal fibre method of working tungsten when used for other materials may result in both small impurity and emf scatter.

The measurement of high temperature thermal emf characteristics II emf scatter. F. W. Kuether. Honeywell. 13pp. Copies available from *Nuclear Power*.

GAS TEMPERATURES

Gas temperatures can be calculated if pressure and density are known and if the molecular weight is also known. In the atmospheric range density can be easily measured and recorded using beta-ray attenuation gauges and the readings may be easily converted to temperature values. Because of the fast response such a system is applicable to the measurement of temperatures in industrial furnaces and should be useful for measuring the temperature of rocket flames. For low densities, electron beam fluorescence probes can be used to determine density which again can be directly converted to temperature values.

Determination of gas temperatures using beta-ray gauges or electron beam probes. B. W. Schumacher. Dept. of Physics, Ontario Research Foundation. 15pp. Copies available from *Nuclear Power*.

Non-nuclear uses for uranium

steel corrosion improved

Research is being undertaken jointly by Eldorado Mining and the Canadian Department of Mines to find commercial uses for uranium in the quantities, and at the price level, which will enable Canadian producers to continue operating after present uranium contracts are completed.

Early experiments indicated that small amounts of uranium added to certain types of steel improved the corrosion resistance and other properties. Development has now reached the stage where the first commercial-size heat of uranium-bearing steel has been topped, rolled and forged. According to Dr J. Convey of the Federal Mines Branch, there is a potential use for at least 1000 tons of uranium a year in this application.

Arrangements are now being made to produce and test carbon superheater steam piping. Recent tests confirm the beneficial effect of uranium on the high temperature creep rupture properties of 0·40% carbon steels. It is considered likely that uranium can modify plain carbon steels equivalent to, or better than, the currently used carbon-molybdenum and carbon-chromium-molybdenum steels.

Work is also under way to produce complex deoxidizers containing uranium, such as a calcium-aluminium-uranium alloy. Other investigations include alloying effects with 12% Cr steels for use at elevated temperature. In the non-ferrous field, work on binary aluminium-uranium alloys so far shows little promise of application. Other studies are being made of the effect of uranium additions to copper and copper alloys.

★ 280

Glove box milling

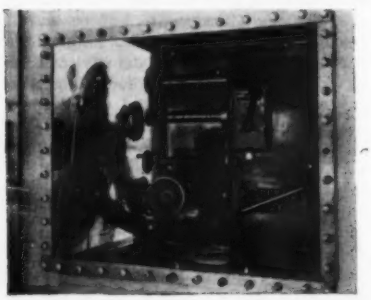
standard machine modified

For milling radioactive materials, Adcock & Shipley have modified their Model 1 machine for use at Dounreay in glove box conditions. A Kopp Variator now provides variable speed control. This, together with the 3 hp motor which drives it, has been taken outside the glove box; the drive to the machine runs through a long shaft with a running seal. The shaft extends into the base and carries a six-groove pulley driving through six belts to another pulley mounted on the spindle.

The Kopp Variator gives a variation of output speed from 480 to 4320 rev/min from a constant input provided by a 1440 rev/min motor. The Vee belts give a 2 : 1 reduction; in conjunction with a back gear, the speed range provided is 30 to 2160 rev/min. This enables speed changing to be made outside the glove box; the lower spindle speed of 30 rev/min is very useful for machining special materials.

For ease of gloved manipulation, ball handles have been replaced with hand wheels, and the knee and cross slide controls have been reversed. Gear box oil changes can be made from outside the cabinet; special hexagonal grease nipples have also been fitted to facilitate grease gun operation inside the cabinet.

★ 281

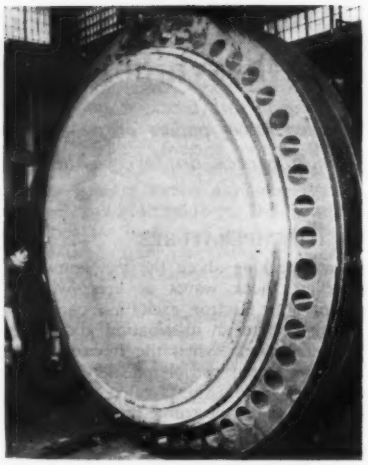


Adcock & Shipley have adapted their horizontal milling machine for use with radioactive materials. The vertical milling attachment remains permanently inside the glove box

Pressure vessel design

effective seals

The pressure vessel of the US Babcock & Wilcox Consolidated Edison 163 MW PWR, 40 ft high × 11 ft diameter, has a net internal volume of 2500 ft³. It is designed to operate at 1800 lbf/in²g and 343°C, and one of the components that required particular manufacturing precision to ensure absence of leakage was the closure head dome.



This 12 ft closure head has been designed for the Indian Point reactor vessel. The dome and flange are SS clad; two 10 ft O-rings provide positive seals

The dome, made by Lukens is from SA212 Grade B steel (6 15/16 in thick) with ss cladding (0·109 in). The closure head flange forging, supplied by Bethlehem Steel, is from SA105 Grade II steel (1 ft 9½ in thick) with ss cladding (3/16 in). It has a diameter of 8 ft 7 in o.d. and 12 ft 2 in i.d. and the total weight is 80,000 lb. Positive sealing is assured by two large metal O-rings, over 10 ft in diameter, fitted in precision machined grooves in the flange. Advanced Products have also made similar rings, but of 8 ft diameter, for the *Savannah* reactor vessel.

★ 282

PATHFINDER PRESSURE VESSEL
This 66 ton pressure vessel for the 66 MW BWR at Sioux Falls, South Dakota, is being given a final radiographic inspection by Allis-Chalmers with their 25 MeV betatron, following stress relief treatment. Capable of penetrating 18 in of steel, the betatron can detect welding defects as small as 0·025 in diameter. Ultrasonic tests were used to detect flaws in the pressure vessel plates before fabrication. After final machining, the pressure vessel is hydrostatically tested at 1050 lbf/in²

★ 283

Sintering active pellets

automatic loading mechanism

An automatic unit for loading individual radioactive metallic pellets into a high temperature vacuum sintering furnace has been designed and manufactured for the UKAEA by Spembly. The magazine, which has a capacity of 36 pellets, has closed ends, and when it is transferred from the glove box to the loading arm of the unit, the door of the inner end of the magazine automatically opens. The loading unit, which is mounted on to the end of the sintering furnace, is sealed and the pressure within the unit and the furnace reduced to 10^{-4} mmHg.

When the correct furnace temperature has been reached, the loading mechanism is put into operation through an automatic programming power unit. The pellets are dropped individually into a cup at the end of the loading arm. This arm, which is provided with a water cooled seal, is then pneumatically fed into the hot zone of the furnace and rotated to deposit the pellet after which it is withdrawn ready to receive the next pellet. An automatic 'pushplate' is fitted at the end of the arm to eliminate pellets piling-up in the furnace.

The pellets are deposited at regular intervals, and counted at the same time. The count is displayed on the Programme Unit where a series of lamps indicate the loading sequence. A warning bell sounds when all the pellets have been deposited. A fault warning system is also incorporated.

The Spembly vacuum sintering furnace loading mechanism consists of a 20V d.c. drive motor, a control valve, two solenoid valves—one for on/off positions and the other for change-over—a rotating loading arm, and an automatic programming power unit

★ 284

Hafnium and zirconium

new separation process

A method has been developed by the National Bureau of Standards that is particularly useful for the determination of zirconium in hafnium base materials. Ordinarily very difficult to distinguish chemically, hafnium and zirconium can now be separated by a single-step anion procedure. The separation for analysis is obtained by using a strong quaternary-amine anion-exchange resin column with diluted (3·5%) sulphuric acid as the eluting solution. After separation of a mixture containing approximately 100 mg each of hafnium and zirconium, spectrochemical examination shows only a few ppm cross contamination.

The sample for the separation is prepared by dissolving it in a sulphuric-hydrofluoric acid solution and then fuming off the hydrogen fluoride. Polystyrene columns, loaded with a commercial anion-exchange resin, are conditioned with a 3·5% sulphuric acid solution. After the diluted sample solution is added to the column, the hafnium fraction and then the zirconium fraction are eluted with a 3·5% sulphuric acid solution. The hafnium and zirconium, in separate fractions, are then precipitated with cupferron, filtered, ignited, and weighed as the oxide.

★ 285

Solid state devices

micro-miniaturization

Recent developments seen at Texas Instruments' new Bedford Factory include micro-miniaturization in the solid state field. An example is the multivibrator of the following dimensions: 0·25 in long, 0·125 in wide, and 0·030 in thick.

Using a normal flip-flop circuit, in this extremely small space, there are six resistors, four capacitors, four diodes, and two transistors. With devices of this size, a component density of 5 to 50 million components per cubic foot is theoretically possible. The factory at Bedford is currently producing silicon and germanium semiconductor devices and transistors. (See also in *Business News* in this issue.)

★ 286

IN BRIEF

SHIELDING TESTS A mobile shielding laboratory in the form of a small van-type truck carrying very sensitive instruments has been developed at ORNL for inspecting the *Savannah* shielding. The truck will be driven aboard the ship.

★ 287

HYDRAULICS RESEARCH Glenfield's new laboratory, recently opened at Kilmarnock, is equipped to carry out hydraulic flow tests on established products, and to provide basic data essential for new designs.

★ 288

FIRE-EXTINGUISHING POWDERS To deal effectively with fires caused by the spontaneous combustion of finely-divided uranium, plutonium and thorium, metallurgists at Dounreay have developed a fire-extinguishing powder. It is a eutectic mixture of dry powdered inorganic chlorides and/or fluorides inert towards the metal involved. The mixture is so chosen that its melting point is below the melting point of the burning metal. This produces local fusion of the powder, a fused skin around the burning metal, and absorption of latent heat.

★ 289

TEMPERATURE MEASUREMENT A new welding process by Spembly has enabled thermocouples with sealed earthed junctions in cable sizes down to 0.010in dia. to be made. Insulated and sealed hot junctions can be produced in cables down to 0.020in dia. at present, but developments should extend the range down to 0.013in.

★ 290

CIVIL ENGINEERING RESEARCH To counter criticism against the civil engineering industry for lack of significant effort in research and experiment, a Research Council was set up towards the end of 1960. An appeal is now being made for finance to support important projects.

★ 291

HYDROFLUORIC ACID RECOVERY A process has been developed by the UKAEA that may have considerable effect on the sale of hydrofluoric acid. By using an amine, flash evaporation, and fractional distillation, hydrofluoric acid in water can be recovered. Better than 99·5% from quite low concentrations is claimed.

★ 292

AUTOMATIC THERMOCOUPLES A retractable thermocouple system for use with vacuum furnaces has been devised at the UKAEA, Risley. Flexible metal sealing bellows supporting the thermocouple collapse under vaccum and thrust the thermocouple junction into the crucible hole. Pressure of the junction on the object in the furnace is regulated by means of an adjustable spring operating against the action of the bellows.

★ 293

FUSION RESEARCH Using the Direct Current Experiment (DCX), the Oak Ridge National Laboratory has succeeded in increasing the containment time for rapidly circulating hydrogen ions in a magnetic field from a few thousandths of a second to as long as three seconds.

★ 294

★ *For further information on any item, circle the appropriate number on the reply card facing page 106.*

New Product Survey

EQUIPMENT · INSTRUMENTS · MATERIALS

INDICATOR WARNING

photo-electric device

For initiating action when predetermined limits of operation are being exceeded, Sealey Engineering has developed a simple instrument warning device. It consists of

The Stanley Sealey instrument warning device is an 'add on' unit for use with standard meters. It may also be used with pen recorders, thermometers and other instruments

one or more photo-electric heads and a control unit. In the event of one or more, or a certain combination, of several limits being exceeded, the device closes a pair of contacts in the control unit. It is 'fail safe' and the contacts may be used to initiate any action required.

The head is approximately $\frac{3}{4}$ in × $\frac{1}{4}$ in × $\frac{3}{4}$ in and when used with a standard meter is merely applied to the glass front of the meter at the predetermined level and below the meter scale. The head is small enough not to obscure the scale in the smallest meter and it can be moved from meter to meter as the need arises.

Many applications are possible. A recent one is the monitoring of a group of oil pump tubes to detect the passage of globules of oil, shutting down the plant if the period between the globules becomes excessive.

★ 208

FUEL ELEMENT TESTING

detecting leaks

Using their mass spectrometer leak detector, 20th Century have developed a composite unit for testing single fuel elements. The additional equipment takes the form of an auxiliary pumping unit connected to a test enclosure. The standard leak detector consists of a vacuum system, and combines a Pirani gauge, an ionization gauge and a mass spectrometer to cover the range of leaks from tens of lusecs to 10^{-7} lusecs.

After the fuel element is internally filled with helium at a reduced pressure, it is loaded into the enclosure; this is then evacuated to a pressure of 10^{-5} mmHg, using the auxiliary pumping system. The enclosure is isolated for a period and then connected to the leak detector. This is tuned to the helium peak to measure the pressure rise over a period of time. Instrument sensitivity is checked by means of a calibrated leak and the complete testing operation takes only ten minutes.

In addition to testing single fuel elements, the pumping system is capable of sampling volumes up to 300l. and the unit can be attached to manifolds of a number of test enclosures for batch production.

The 20th Century fuel element testing instrument consists of a mass spectrometer leak detector, an auxiliary pumping unit and a test enclosure

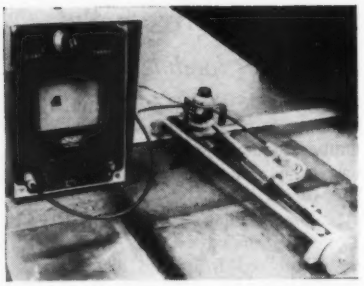
★ 209

WELD INSPECTION

ultrasonic scanner

Higher speeds in weld inspection and lower costs are claimed by Branson for their 'Sonoray 5' ultrasonic-type test equipment. Using a cathode ray tube, flawless welds show up as a series of pyramid markers, an exact replica of the rebounding sound beam within the plate and weld. Obstacles such as a slag inclusion, lack of fusion, or hairline cracks as small as 1/16in will generate a vertical pip on the scope at the exact flaw location.

Ultrasonic energy is pulsed into the metal under test by means of a transducer, which changes the electrical oscillations of the Sonoray into identical mechanical vibrations. Because the transducer is held at an angle to the plate, the sound beam enters at an angle and rebounds inside the plate until eventually all its energy has been dissipated. Any discontinuity within the metal or the weld reflects some or all of the sound beam—depending on size of flaw—returning it along its original path, back to the transducer.



Advantages claimed for the Branson ultrasonic-cathode ray tube equipment are higher speeds in weld inspection and lower operational costs

To simplify flaw location, the 'Sonoray' screen shows a zig-zag trace, which is an exact replica of the sound path within the metal. Any returning echo, sensed by the transducer, causes a large dot to appear at some point along the trace. The transducer is then moved to cover the suspect weld area, and it will effectively generate a series of closely-spaced dots, outlining the flaw. An electro-mechanical linkage between the transducer and a precision potentiometer makes it possible to locate the flaw accurately, within minutes.

★ 210

PIPELINE CONTROL

automatic valve operation

Suitable for the remote control of pumps and valves at unmanned stations in a liquid pipeline, the Dressler system, in manufacture by Rotax, uses solid-state printed-wiring equipment, assisted by the central display and printer logging of alarms and variables, e.g. pressure and flow, measured by instruments at the stations.

Digital techniques are employed through-

A typical control centre for a pipeline with four unmanned pumping stations. Automatic operation is effected by digital techniques

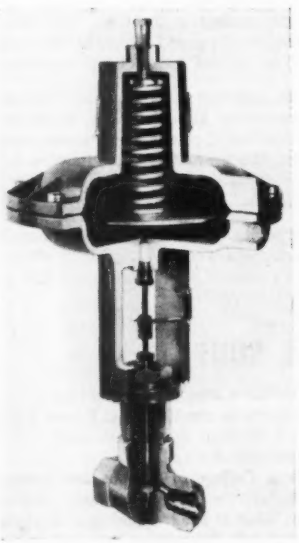
out the telemetry and telecontrol equipment. The heart of each slave station is an analogue-digital converter which takes the outputs of various pressure, speed, and temperature transducers, usually d.c. voltages, and converts them, when required by the received address code, to digital numbers of three significant figures, which are then transmitted. The controller can, at will, initiate an on/off change at any slave station without stopping the logging scan in progress.

★ 211

FLOW CONTROL VALVE

pilot plant use

The *Minim* valve, now marketed in the UK by G. A. Platon, is a scaled-down version of the industrial diaphragm control valve, and it is intended for the control of



Suitable for flow control in laboratory pilot plant is the 'Minim' miniature diaphragm valve made by Platon

small flows, mainly in research and pilot plant work.

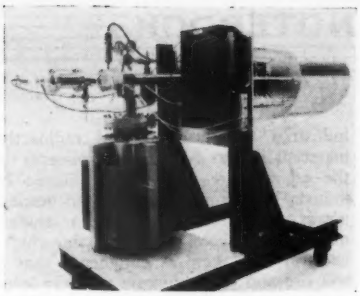
Made in sizes of ¼ in and ½ in reliable behaviour can be expected; manufacturing precision is such that the C_v value is as small as 0·0000018. Valve trims are widely interchangeable and are made from a variety of corrosion resistant materials. Equal percentage, linear and quick opening characteristics are available. Standard items include air-to-open or air-to-close topworks, cooling bonnets and bellows stem seals.

★ 212

NEUTRON GENERATOR

activation analysis facility

Nuclear - Chicago's neutron generator model 9500, is a positive ion accelerator capable of producing a continuous output of 4 x 10^{10} n/s. With a suitable moderator, a thermal neutron flux of 5 x 10^{7} can be obtained, sufficient for activation analysis of practically all elements. The unit is supplied with a 150,000 V power supply and a synchronous-motor control console. Output voltage can be varied continuously from 0-150kV.



The new Nuclear-Chicago neutron generator produces a continuous output of 4 x 10^{10}n/s

The continuous output accelerator employs a high power r.f. type ion source which has an atomic/molecular ratio of 9:1, capable of delivering in excess of 1·0mA of beam current. A VacIon pumping assembly provides a clean vacuum of 10^{-7}mmHg. Safety interlocks guard against accidental grounding of the high voltage terminal. The operator console controls are electro-mechanically coupled to the accelerator by means of synchronous motors.

★ 213

IN BRIEF

• **Double-beam oscilloscope.** Solartron's first rackmounted double-beam oscilloscope, the CD 1016, has two identical Y amplifiers, and a bandwidth of d.c. to 5 Mc/s (–3 dB), with a rise time of approximately 70μ. Nine calibrated sensitivity ranges, switched in 1—2—5 sequence, cover 100 mV/cm to 50 V/cm with ±5% accuracy. In addition, a fine control gives continuous coverage up to approximately 100 V/cm.

★ 214

• **Dry lubrication coatings.** Dry-film bonded coatings of molybdenum disulphide are useful for solid lubrication both during running-in and for very severe operating conditions. 'Moly-VI-Bond' marketed by K. S. Paul can be applied by brushing or dipping to metallic or non-metallic surfaces and will cure naturally at room temperature or more rapidly if heated.

★ 215

• **Flaw Detector.** A new gamma ray image intensifier system introduced by Zenith Radio detects minute flaws in 4 in thick steel and other dense objects, and projects images of the flaws on to a television screen. Used in conjunction with a camera and a cobalt-60 unit, the new intensifier tube provides for assembly line continuous inspection of dense materials.

★ 216

• **Neutron detector.** A new slow neutron detector NE 421 of Li_6F is now available from Nuclear Enterprises with detection efficiencies of up to 60% for thermal neutrons, a value which is about double that obtained with boron-10 detectors.

★ 217

• **Multi-range meter.** The new portable Gossen Meter, type UPHI, introduced by Aveley is designed for the measurement of a.c. voltage, real and reactive current, power factor, frequency, resistance, apparent phase-angle and reactive powers. The following full scale readings are provided: 12–600 V, 60 mA–120 A, 1 Ω–100 K Ω multi-range, ±90° (cos Q sin Q) at 400 c/s and 4 Kc/s.

★ 218

• **Vacuum pumps.** The 'Reciprotor' combined vacuum/pressure pump marketed in the UK by Edwards High Vacuum is compact, weighs 10 lbs and supplies oil-free air. Type 406G, for continuous operation, provides a free air displacement of 1·62 ft³/min, a vacuum of 18 in Hg and a maximum pressure of 7·8 lb/in². Type 606G, for intermittent operation, delivers air at 1·77 ft³/min and attains a vacuum of 22 in Hg and a maximum pressure of 10·7 lb/in².

★ 219

• **Analogue computer control.** Available from Hagan Controls is a range of entirely solid state analogue computer control systems of advanced design. These PowerMag systems employ magnetic amplifiers in an electric analogue technique and are designed to complement digital computer control.

★ 220

• **Closed circuit television.** Specifically designed for use with their 12 in X-ray image amplifier, the Marconi ciné-recording unit, type TF 1323A, can be used with closed circuit television and for monitoring continuous industrial processes. The equipment mainly comprises a television monitor with a 17 in screen, a ciné-camera (either a 16 mm Paillard Bolex, or a 35 mm Newman Sinclair), and a camera drive. Alternative lenses enable either the whole or a reduced area of the television screen to be recorded.

★ 221

• **Diamond coated tools.** Dia-Chrome Inc. have announced a new line of diamond coated tools suitable for short run jobs or applications using very thin material that do not justify the more expensive long life heavy duty tools.

★ 222

• **Airtight ducting.** Hargreaves have commenced production of lockformed spirally-wound airtight ducting which has the advantages of greater rigidity, fewer joints and 40% weight saving. Using either aluminium or galvanized, mild, stainless and plastic-coated steel, sizes can be obtained ranging from 3 in-32 in diameter and up to 20 ft in length.

★ 223

• **Level control.** The LR8 series of multiple level control panels, recently introduced by Elcontrol, provide for the control of from two to twelve sets of level and can be used with the standard range of probe fittings.

★ 224

★ *For further information on any item, circle the appropriate number on the reply card facing page* 106.

STUDENTS' NOTEBOOK

GROUNDWORK—Teaching

1—The contribution of the College of Advanced Technology

The Colleges of Advanced Technology are making a useful national and international contribution in the training of future designers, operators and administrators of power reactors: at Birmingham, Bradford and Salford in particular. It is here that the first part of the international AERE Reactor Course is held. The nine colleges, created in 1956, have worked under difficulties in bringing the level of their work up to university standards, the principal one being the recruitment of suitable staff. A significant change in status, however, is promised; according to a recent announcement in the House of Commons by Sir David Eccles, the Minister of Education, the Colleges of Advanced Technology are to be transferred from local government authorities to independent governing bodies; direct grants are to be received from the Ministry, and new salary scales are to be related to those of the universities.

The varied nature of the training offered is typified by the work done at Birmingham. In addition to the Diploma of Technology courses (on Electrical and Mechanical Engineering, Applied Physics, etc.), short courses in nuclear technology are offered to postgraduates. The six weeks pre-Harwell course, now to be extended to nine weeks, is very intensive and deals mainly with the fundamentals of reactor physics (40% of the syllabus) and nuclear engineering (20%), together with a background of mathematics (6%), electronics (6%), chemical engineering (6%), metallurgy (6%), economics (3%) and health physics. It also includes an extensive programme of experimental work in the nucleonics laboratory and on engineering rigs. For senior executive staff there is a one week course of some 18 lectures covering reactor physics theory and the chemical, metallurgical and economic aspects. A practical evening course on the industrial applications of radioactive materials is also available. Enrolments for the courses are very much affected by industry's fluctuating interest in nuclear power. The recent trough in student numbers for these subjects is thought to be over and there is confidence that it will rise and then maintain a steady level.

Considerable emphasis is placed on experimental work and there is interest in providing research facilities approaching university level. Unfortunately without extra staff, this facet of Birmingham's programme cannot be given its right place; time has to be found in an already tight lecturing schedule to try out experiments and compile laboratory instructions. The implications of the change in status and the completion of the £9 million building should, however, eventually enable the College to segregate its experiments—the elementary from the advanced, radioisotope applications from basic nucleonic equipment.

Nevertheless, Birmingham have made impressive progress in the provision of suitable equipment. When the nucleonics laboratory was formed some 3½ years ago only 12 experiments were established. The number has now grown to more than 60 with many more under development. Whilst scalers, meters, monitors, etc., are purchased commercially, the College prefers to make its own 'ideas' equipment: e.g. Millikan's apparatus for the determination of the electronic charge, methods of finding e/m, etc. They are also thinking of designing their own Van de Graaff accelerator and a start has been made on a subcritical assembly. There is talk too, about purchasing a reactor simulator, and the College will share a research reactor with the University, once the siting and finance aspects are approved. At the moment, the Triga is favoured on account of its pulsing facility.

Experimental flexibility must have the support of a good workshop, however; in this direction the Physics Department is fortunate—an academic staff of 20 keeps six technicians fully occupied. Whilst available equipment and staff are limited by university standards, the Birmingham College welcomes forms of sponsored research particularly in the development of new technologies and the application of existing scientific knowledge.

A few of the 60 or more experiments in the nucleonics laboratory at the Birmingham College of Advanced Technology, with the 'Nuclear Power' chart of Berkeley and another of Calder Hall in the background. The apparatus shown covers experiments in powder mixing, radiography, thickness gauging by beta backscatter, and the examination of alpha tracks in nuclear emulsion.

NEWS

• Northwestern University, Illinois, is having a new materials research centre and additional physics facilities costing around $7½ million that will result in the doubling of the current levels of graduates, faculty and research into solid state materials. Expanded research work in this field and in high energy and low energy physics will be assisted by a 5 MeV Van de Graaff accelerator and access to the $42 million synchrotron at nearby Argonne.

• IBM intends to found three Research Fellowships, one for each of the years 1961-3, tenable at any university or university college in the UK. They will be of sufficient duration to allow serious research and no subject restriction is to be made.

• In response to the many requests for information about nuclear radiation and radioactivity, presented in a non-technical form, the USAEC has compiled a booklet entitled: '18 questions and answers about radiation'.

• Faculty members of the University of Michigan are to investigate the effects of a ship's motion on boiling water reactors.

UK COURSES

Battersea College of Technology Corrosion Problems in the Electrical Power Industry: 8th Corrosion Summer School, 25th-28th September, Fee: £10.

Bristol College of Science and Technology Postgraduate short courses, September 1961/March 1962: Analogue Computing, 12 lectures, Wednesday evenings commencing 13th September; Nuclear Physics, 10 lectures, Tuesday evenings commencing 10th October; Reactor Physics and Reactor Technology (details to come). Fee: each course £2 2s. Also various week-end courses, including: Metal finishing, Non-destructive testing, Thermal stresses, Servo-systems, Porous surfaces, etc. Also special courses: Radiobiological Health and Safety, 20th October-22nd December, Fee: £25; the Teaching of Radiochemistry and Nuclear physics in Secondary schools, 30th October-2nd November.

Leicester College of Technology and Commerce Radiochemistry, 6 months course commencing October, Fee: £30.

Liverpool College of Technology Radiochemistry, 2 weeks course commencing 16th October, Fee: £12; Radiation Safety and Health Physics, 2 weeks course commencing 18th September, Fee: £12; Radiobiology: 2 weeks course commencing 28th August, Fee: £12.

Harwell Reactor School Senior Technical Executives course; Control and Instrumentation of Reactors course. Both are for 5 weeks commencing September, Fee: £52 10s.

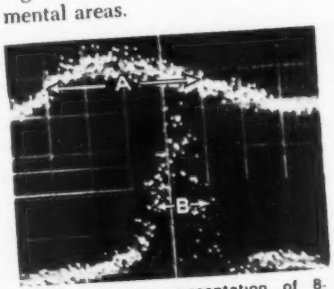
High Voltage Engineering Corporation . . .

"CHARGED PARTICLES"

Nanosecond Pulsing

The timing of nuclear events and the discrimination between them continues to be a major hurdle for the experimental physicist.

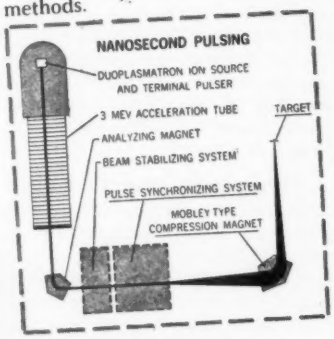
We don't need a market research program to reveal the need for apparatus which will assist the experimenter to do accurate neutron time-of-flight work or to determine excited state lifetimes in the milli-u-sec. region. Ultra-short high-intensity pulses of charged particles, and the resulting neutron bursts, provide one of the most promising techniques in these experimental areas.



Lumatron scope presentation of 8-nanosecond terminal-pulsed beam (A) and compression to 2-nanosecond post acceleration pulse (B).

We have completed the development of a system for producing and measuring *pulsed proton beams with an intensity of several milliamperes and a pulse duration of less than one nanosecond (10⁻⁹ seconds).* The first research results from this apparatus are soon to be reported.[1]

The beam is accelerated to 3-Mev by a Van de Graaff fitted with a terminal pulser of the deflection type, delivering ion pulses of 10 ns duration every 1000 ns at the input end of the acceleration tube. After acceleration, the pulse is compressed by a 90° double-focusing Mobley[2] magnet whose radius of curvature is 30 inches. The deflection electrodes at the entrance of the magnet are driven by a 10 Mc sinusoidal voltage which is synchronized with the pulse from the accelerator. Observations were made with a time-to-pulse-height-conversion measurement system checked by nuclear methods.



[1] *L. Cranberg, et. al., to be presented at Am. Phys. Soc. Meeting, New York (February 1961)*

[2] *R. C. Mobley, Phys. Rev. 88, 360 (1952)*

Isotopes of Rare Purity

The need for pure isotopes in work concerned with nuclear structure and particle reactions has led us to develop a new, broad-range electromagnetic isotope separator that is faster, simpler to use and provides purer samples than any comparable equipment we've seen.

This instrument is designed to produce up to 10 microamperes of individual particle beams — *with a mass resolving power better than 400.* Separation is achieved in a 5000-gauss, 160 cm radius magnetic field. Time for recovery of samples after collection is less than two minutes. Those who have had their decay schemes disappear before their eyes will appreciate this bit of engineering in working with short-lived isotopes.

The instrument can also be used to produce nuclear targets for studies of energy level, scattering, neutron cross-section or other phenomena, as well as pure radioactive tracers. Two of these instruments are now being built for U.S. atomic energy program. Specifications for the machine are presented herewith.

160 CM ELECTROMAGNETIC ISOTOPE SEPARATOR

Range:	Atomic mass 1 to 400
Current:	$10\mu a$ of most abundant isotope ($100\ \mu$ achievable with some loss in resolving power)
Voltage:	80 kv
Magnetic Field:	5000 gauss
Field Stability:	Better than 01 per cent
Ion Sources:	Modified Arc
Operation:	Time for removal of collector after full operation — 2 minutes!
Vacuum System:	All metal bakeable gasketing

Accelerator Conference

The 2nd Accelerator Conference held recently in Amsterdam was a rewarding occasion for High Voltage and its Dutch affiliate, High Voltage Engineering (Europa) N.V. Three hundred participants from 24 countries joined in this exchange of information on accelerators and experimental techniques. There was some healthy give and take between the "ideal" machine described by physicists and the "present state of the art," reported by our engineers. If there were no gap between what is wanted and what is commercially available, most of us could pack up and go home.

As things stand, High Voltage continues to push its development to the limit and is glad to share a challenge with its insatiable customers in research.

The Conference Proceedings were published in a January special issue of *Nuclear Instruments and Methods.* Check with your librarian, or write us for a complimentary copy.

HIGH VOLTAGE ENGINEERING CORPORATION

BURLINGTON, MASSACHUSETTS, U.S.A.

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APPLIED RADIATION CORPORATION

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HIGH VOLTAGE ENGINEERING (EUROPA) N.V.

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Circle **No 49** on reply card for further details

ISOTOPE REVIEW

NEW TECHNIQUES

Two new isotope generators

One of the more spectacular applications of radioisotopes has been their use in an ' atomic battery ' in a US satellite launched on June 29. This generator is one of the series of SNAP (Systems for Nuclear Auxiliary Power) devices being built for the US Atomic Energy Commission by The Martin Company.

It is an isotopic device similar in principle to the SNAP-3 generator first demonstrated by the USAEC in January, 1959 (see *Nuclear Power*, October 1960, page 81). Shaped like an elongated sphere, the new SNAP generator is about 5 in in diameter and 5½ in high. Its fuel is plutonium-238 whose heat (released by spontaneous decay) is transformed directly into electrical energy by a thermoelectric system. The power, about 2·7W, is being used by the satellite's instruments and by two of its four transmitters. The 4·7 lb unit operates without any moving parts and since plutonium-238 has a half-life of 89.6 years, it is theoretically capable of powering a space transmitter for a long time.

The choice of plutonium-238 was dictated by the relatively easy shielding needed to contain the ' alpha ' particles and also its long half-life. The generator has been so designed that it will burn-up and disintegrate into particles only about one-millionth of an inch in diameter. Such particles will take many years to reach the earth and their activity then will be far too small to measure with existing instruments, says the Martin Company.

Another Martin Company isotope-fuelled generator, this time using strontium-90 as a fuel, was demonstrated by the USAEC recently. It will be used as a weather station and is to be shipped to the Arctic. This unmanned weather station derives its 5W power from 17,500 curies of strontium-90 in the form of strontium titanate pellets (about 1 lb). (Next month's ' Isotope Review ' will carry a full description.)

The tiny SNAP generator being fastened to the base of the TRANSIT satellite for tests.

US californium project

A project for producing ' relatively ' large quantities of plutonium 242, americium 243 and curium 244 is underway at the USAEC's Savannah River plant. It is expected to be completed by 1963. The isotopes produced will be further irradiated in a new high flux reactor under construction at Oak Ridge National Laboratory. This irradiation programme is to produce greater than milligram quantities of californium.

Amersham extends range

The AEA Radiochemical Centre at Amersham, which previously prepared Beryllium-7 only to order, now proposes to supply a standard product on a millicurie basis. Batches will be produced at three monthly intervals and delivery will normally be from stock. The price will be: up to 200μc—£10; £25 per mc thereafter.

It was also announced by the Centre that Diodone I-131, which provides a rapid and reliable means of investigating kidney and urinary tract abnormalities, will be produced in batches at two-weekly intervals and delivery will normally be from stock. Price: £10 for the first mc and £3-10 per mc thereafter.

Indian plant study

The Indian Atomic Energy Commission has approved a £1500 scheme to investigate the role of micro-biology in plant life by use of a radioactive source. Heading the project will be Dr G. Rangaswamy, professor and head of the Department of Agriculture, Annamalai University.

Tumour localization Localization of brain tumours by a photoscanner, a device for ' seeing into ' the body with the help of a radioactive substance, has been introduced into the United Arab Republic under an International Atomic Energy Agency technical assistance project. It is believed to be the first time this technique has been used successfully for brain tumour localization outside the North American continent, says the IAEA.

NEWS ROUND-UP

US plans million curie sources

The AEC has announced that it is establishing facilities at its Hanford plant to produce million-curie radiation sources by mid-1963 for sale to private companies. To be made available will be strontium-90, cesium-137 and cerium-144 fission product sources. If demand develops, zirconium-95 and promethium-147 will also be supplied. The AEC say that it considered a formal invitation to industry to undertake the recovery operation but decided it was more feasible for the AEC to recover fission products and offer them to industry for final processing, fabricating and marketing.

Rumanian industrial plans

Extending its range of special installations and instruments using isotopes is the Rumanian Institute for Nuclear Physics. The Institute has, for instance, supplied 25 units to the steel industry to ascertain the wear of blast furnace linings and other instruments to industry to control welded material. Further applications are planned.

Activation analysis A deutron accelerator is being used by Shell Development Company scientists at their Emeryville, California, laboratories for activation analysis. The advantage claimed over using a Van de Graaff accelerator is cost—about $20,000 against $140,000—and detection of at least nine more elements. Shell says Emeryville is believed to be the only industrial laboratory using semi-automatic activation methods as a matter of routine; they envisage using the equipment as a potential tool in control laboratories at refineries and chemical plants.

Nuclear calibrators Tracerlab of Waltham, Massachusetts, has a $34,000 contract to supply nuclear calibrators to the Office of Civil and Defense Mobilization.

Beta gauges Tracerlab Export Sales has shipped two beta gauges to the Oy Control Corporation, Finland, for incorporation into paperboard manufacturing machinery being made for Russia.

Sterilised hypodermics The Package Irradiation Plant at the AEA's Wantage Research Laboratory is being used to sterilise batches of plastic hypodermic syringes being supplied by Bailey's Sterile Syringes Ltd for anti-polio injections in the Liverpool area.

Technetium-99 Oak Ridge National Laboratory has reduced the price of technetium-99 to $100 per gram with a minimum charge of $10 for one-tenth of a gram or less. The previous price was $1600-$2800 per gram.

USEFUL READING

Radioisotopes in World Industry, Abstracts of Selected Foreign Literature, USAEC, Report TID-6613. Available from the Office of Technical Services, US Department of Commerce, Washington 25, DC, USA. Price $2.50.

Abstracts, Southern California Industrial Radioisotopes Conference, January 25-27. Contact, Western Gear Corporation, Box 182, Lynwood, California.

Radiological Health Handbook, USAEC. Available from Office of Technical Services, US Department of Commerce. Price $3.75.

Radioisotopes in Soils, Cells and Space, Glenn T. Seaborg, chairman, USAEC; **Radiography in the Fabrication & Manufacture of critical equipment,** Walter B. Hester, director of engineering, & Herman Geller, senior mechanical engineer, The Stearns-Roger Manufacturing Company, Denver, Colorado; **Radioisotope Applications at the Kennecott Copper Corporation,** W. M. Tuddenham, head, analytical services and special studies and H. W. Franz, Project development engineer, Western Mining Division Research Center, Kennecott Copper Corporation, Salt Lake City, Utah. All were papers presented at the American Mining Congress meeting held at Denver, Colorado, in April.

Radioisotopes in Industrial Process Control, Oscar M. Bizzell, chief, Isotopes Technology Branch, Office of Isotopes Development, USAEC. Paper presented at the Joint Chemical Engineering Congress, American Institute of Chemical Engineers, Cleveland, Ohio, May 7-10.

she can't have one without the other

Most people want the comfort of modern amenities—but few like the towers that bring the power to work them. What's the answer? Return to lamplight, peat fires and the washing tub? Bury the power lines and do away with the towers altogether? Attractive idea—just possible too, but at 17 times the cost —with its inevitable effect on your electricity bill. For the foreseeable future, transmission towers must stay. But they cannot be planted just anywhere. An Act of Parliament charges the Central Electricity Generating Board with a double duty: to provide an efficient and economical electricity supply, while preserving visual amenity as far as possible. Power lines are planned with forethought—by men who are as anxious as you are to keep this land green, pleasant . . . and up-to-date.

■ These advertisements are appearing in the farming and country magazines. The Central Electricity Generating Board thank electrical contractors for their co-operation in the past, and know that they will do all they can to preserve the amenities of the countryside.

C.E.G.B

who make and supply electricity to 12 Area Electricity Boards in England and Wales (which re-sell to consumers) and British Railways.

Write for a copy of "Preserving Amenities" to The Central Electricity Generating Board, 83 Winsley Street, London, W.1

PROF. M. G. KENDALL joins C-E-I-R

People

by John Radford

L. A. THOMAS chief physicist

UP FROM 'Down-Under' were five Australian scientists visiting the UK. First on the list is **Dr U. Englebert,** deputy head of the Isotopes Production Division of the AAEC, who arrived at the end of June for a seven-day stay during which British isotope production methods and developments were reviewed. Also on a short stay was **R. M. Fry,** head of the Physics Division. He led the Australian delegation to a conference in Vienna on health and safety and visited the UK for ten days prior to his return to Australia. Two other short visits were made by **B. S. Hickman,** senior metallurgist, AAEC, who discussed research in his field with AEA officials and **Maurice C. Timbs,** Acting Executive Commissioner, who had three-day talks with AEA officials before returning home via the USA. Staying on till August 5 is **Dr Alan Draycott,** senior engineer, AAEC, who arrived in the UK on June 21. His speciality is the engineering side of nuclear power stations and during his stay, he visited several AEA and industrial research establishments.

Another official visitor to the UK was **Mr Masanousuke Ikeda,** Japanese Minister of State and President of the Atomic Energy Commission. He spent three days in Britain to 'buy the remainder of the equipment' for the Tokai-Mura reactor and to arrange for more Japanese scientists and engineers to come to the UK for training. This visit was Mr Ikeda's first stop on a one-month tour covering West Germany, France, Belgium (Euratom), Canada and the US. While at Euratom with the other three members of his team, Minister Ikeda formally invited the President and members of the Commission to visit Japan in the near future.

The chief physicist at the Hirst Research Centre of the General Electric Company Ltd, Wembley, Middlesex, is to be **Mr L. A. Thomas** (44). He will be a member of the staff of the GEC Central Research Laboratories with special interest in the programmes of long term and fundamental research. Mr Thomas joined the Research Laboratories in 1935 and was appointed head of the Materials and Components Division in 1960. He retains his responsibilities in this field of the work of the Centre.

Joining the board of C-E-I-R (UK) Ltd, the computer research organization on October 1, 1961, is **Professor Maurice G. Kendall,** at present Professor of Statistics in the University of London. He will be responsible for the Departments of Mathematics, Statistics and of Operational Research and their activities. Professor Kendall is the president of the Royal Statistical Society and a past-president of the Operational Research Society.

Dr Charles Manders, who has been with the Ministry of Defence on scientific duties, has been appointed by the DSIR to the new post of Scientific Attache to the British Embassy in Tokyo. **Mr William Drury** joins the Embassy in Stockholm in a similar capacity.

BUSINESS NEWS

DUNGENESS ORDERS **Matterson Ltd,** mechanical handling engineers of Rochdale, are completing an order for four overhead cranes each of 20 ton capacity for **The Nuclear Power Group's** Dungeness station. The four cranes, valued at about £23,000, are for use as blower house cranes and are due for delivery early in 1962.

Another order for the Dungeness station, this time for £300,000 worth of electrically-welded finned steel tube, has been received by the Tube Investment Company, **Tube Products Ltd,** of Oldbury, Birmingham. This follows contracts for similar extended surface welded tubing, to a total value of over £2 million, placed with Tube Products for the Hunterston and Trawsfynydd nuclear power stations; the Latina project in Italy and the Tokai-Mura project in Japan. Tube Products pioneered the development of this type of extended surface tubing some three years ago and has already supplied over two million feet of the material.

BOILER FIRMS MERGE Another merger, this time between the **Superheater Company Ltd,** and **International Combustion (Holdings) Ltd,** illustrates the grouping and pooling of resources among manufacturers resulting from the trend towards fewer but larger boilers. Superheater (largely owned by the US **Combustion Engineering Inc.**—itself a close friend of the International Combustion Group) has become increasingly dependent for orders on International Combustion. All three boards are happy about the arrangement and Superheater will keep its identity.

• The GEC and **Thompson Ramo Wooldridge** of the US have set up a new company —**International Systems Control Ltd**—to market industrial process control systems in Britain, the European Free Trade Area and the Commonwealth.

• **Texas Instruments Ltd** has opened a new plant specially designed for the manufacture of transistors and other semiconductor components. Sir John Cockcroft performed the opening ceremony. (See Research and Development, this issue.)

• The **Plessey Company Ltd,** following an agreement with **P. R. Mallory and Company Inc,** is now manufacturing a range of solid electrolyte tantalum capacitors.

• The GEC and **Richardsons Westgarth & Co Ltd** have pooled their resources for the design, development, sales and manufacture of heavy electricity generating and industrial power plant.

• Work is now proceeding on the nuclear compartment equipment for Britain's second nuclear submarine, says **Rolls-Royce Ltd's** annual report.

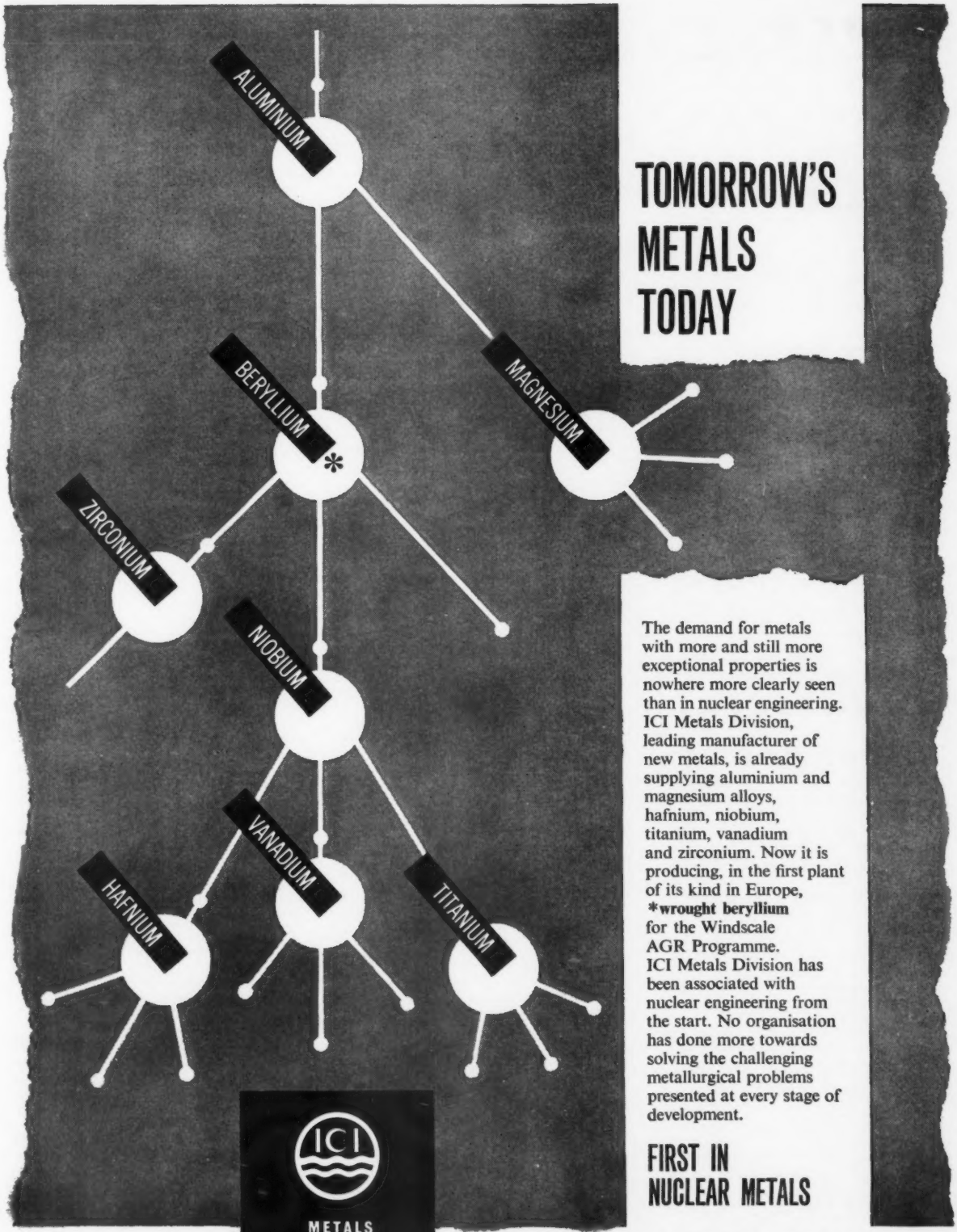
OVERSEAS

JAPANESE TO RECEIVE BR-2 INFORMATION Under a technical information agreement signed with the **Nuclear Development Corporation** of America, **Sumitomo Atomic Energy Industries Inc.** of Japan is to receive details on the design, construction and operation of the BR-2 materials testing reactor nearing completion at Mol in Belgium. The reactor was designed by NDA and **Belgonucleaire**; the latter company is a participant in **NDA-Europe.**

• A long term marketing and manufacturing agreement has been signed between **International Computers and Tabulators Ltd** and the **National Data Processing Corporation** of Dallas, USA. Under this, NDP products will be added to the ICT range of equipment.

• A £2500 research contract for the study of methods of recovering beryllia from beryl has been awarded by the Australian AEC to the **Australian Mineral Development Laboratories.**

• The **Kyokuto Boeki Kaisha** organization of Tokyo has been appointed exclusive agents for **Solartron Electronic Group** products in Japan.



TOMORROW'S METALS TODAY

The demand for metals with more and still more exceptional properties is nowhere more clearly seen than in nuclear engineering. ICI Metals Division, leading manufacturer of new metals, is already supplying aluminium and magnesium alloys, hafnium, niobium, titanium, vanadium and zirconium. Now it is producing, in the first plant of its kind in Europe, ***wrought beryllium** for the Windscale AGR Programme. ICI Metals Division has been associated with nuclear engineering from the start. No organisation has done more towards solving the challenging metallurgical problems presented at every stage of development.

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Diary

24–28 JULY
Gordon Research Conference, **Corrosion and oxidation of metallic surfaces,** New London, USA. Details, W. G. Parks, Director, University of Rhode Island, Kingston, R.I., U.S.A.

27 JULY–1 AUGUST
International symposium on **macromolecular chemistry,** Montreal, Canada. Details, Dr R. Morf, c/o Sandoz Ltd., Basle 13, Switzerland.

31 JULY–4 AUGUST
International Congress of Biophysics, including session on **radiation biophysics,** Stockholm, Sweden. Details, B. Londstrom, Karolinska Institutet, Stockholm 60, Sweden.

31 JULY–12 AUGUST
Electric Power Seminar, including sessions on prospects and problems of nuclear power, Mexico City, Mexico. Details, UN Commission for Latin America, Avenue Providencia 871, Santiago, Chile.

1–12 AUGUST
International trade fair, Sydney

2–5 AUGUST
21st conference, International Union of Pure and Applied Chemistry, Montreal, Canada. Details, Dr R. Morf, c/o Sandoz Ltd, Basle 13, Switzerland

3–11 AUGUST
IAEA seminar, **physics of fast and intermediate reactors,** Vienna, Austria

6–12 AUGUST
International **congress on pure and applied physics,** Montreal. Arranged by International Union of Pure and Applied Chemistry. Details, Prof. Leo Marion, National Research Council, Ottawa 2

10–16 AUGUST
International Union of Biochemistry, fifth international **biochemist congress,** including section on **radiation effects on biochemical processes,** Moscow. Details, Professor R. H. S. Thompson, Secretary General, Int. Union of Biochemistry, c/o Department of Chemical Pathology, Guy's Hospital Medical School, London, SE1

14–19 AUGUST
Symposium on **radiation,** International Association of Meteorology, and Atmosphere Physics, Vienna. Details, World Meteorological Organization, 1 Avenue de la Paix, Geneva, Switzerland

15–17 AUGUST
Cryogenic engineering conference, Ann Arbor, Michigan, USA. Details, K. D. Timmerhaus, Secretary, Cryogenic Engineering Conference, Chemical Engineering Department, University of Colorado, Boulder, Colorado, USA

20 AUGUST–6 SEPTEMBER
Tenth Pacific Science Congress, including symposia on **radioactive tracers in oceanography** and on **isotope applications in the Soil/Crop Sciences,** Honolulu, Hawaii, USA. Details, H. J. Coolidge, 10th Pacific Science Congress, Bishop Museum, Honolulu, Hawaii, USA

21–31 AUGUST
UN conference on new sources of energy, Rome, Italy.

21 AUGUST—2 SEPTEMBER
Tenth **Pacific Science congress,** Honolulu. Details, Secretary General, 10th Pacific Science Congress, Bishop Musium, Honolulu 7

23–26 AUGUST
Eighth international annual conference of the Institute of Management, Brussels. Details, Max Duval, Office Belge pour l'Accroissment de la Productive, 60 rue de la Concorde, Brussels, Belgium

28–30 AUGUST
Symposium on **University use subcritical reactors,** Gatlinburg, Tennessee. Details, Symposium Office, University Relations Division, ORINS, PO Box 117, Oak Ridge, Tennessee, USA

28 AUGUST–1 SEPTEMBER
Fifth international conference on **ionization phenomena in gases,** Munich, Germany. Details, Prof. P. Schulz, Technische Hochschule, Hertzstr. 16, Karlsruhe, Germany

28 AUGUST—1 SEPTEMBER
International **heat transfer conference,** Boulder, Colorado. Details, S. P. Kezios, c/o American Society of Mechanical Engineers, 38 West 39th Street, New York 18

28 AUGUST–2 SEPTEMBER
Eighth Congress of the European Society of Haematology, including sessions on marking of blood cells with isotopes, blood change through radiation, plasma chemistry, Vienna. Details, Secretary General, Eighth Congress of the European Society of Haematology, Frankgasse 8, Billrothhaus, Vienna IX, Austria.

AUGUST/SEPTEMBER
Symposium on the **use of radioisotopes in pharmacology,** Stockholm, Sweden. Details, Prof. C. G. Schmiterlow, Dept of Pharmacology, Royal Veterinary College, Stockholm, Sweden.

30 AUGUST–10 SEPTEMBER
St. Eriks Fair, Stockholm

4–8 SEPTEMBER
IAEA conference on **Plasma physics and controlled nuclear fusion research.** Location undecided.

4–9 SEPTEMBER
Third international sessions of the International Association for **Analogue Computation,** Belgrade. Details, Yugoslav Committee for Etan Terazije, 23/VII Belgrade

Industrial Literature

Hydrogen-cooled generators. Design developments of the modern simple hydrogen system for machines with hydrostatic thrust-type seals is one of the subjects discussed in the current Allis-Chalmers ' Electrical Review '.

★ 244

Measuring high voltage. The importance of impulse voltage measurement and the problems arising from the establishment of sphere gap standards are examined in the April issue of ' Co-operative Electrical Research '.

★ 245

Thickness measurement. The current issue of the Tin Research Institute's quarterly journal contains a description of an American method, ' Quantrol ', which continuously gauges the thickness of tin coatings. It relies on analysis of the fluorescent radiation emitted by the tinplate strip travelling under a beam of X-rays.

★ 246

Cooling towers. A recent brochure from Head Wrightson outlines the services offered in the supply of industrial air-cooled heat exchangers and cooling tower installations.

★ 247

Gas seals. Crane Packing's Bulletin No. 24 gives detail of their latest developments in the design of mechanical shaft seals for gas services.

★ 248

Measuring radiation damage. In the study of radiation damage to pressure vessel structural materials, there is the need for effective methods and instrumentation which can determine the temperature of the transition from brittle to ductile behaviour. In the April number of ' Solus-Schall News ' Dr Förster describes in detail a method he has developed for the measurement of the modulus of elasticity, the torsional modulus, and the damping capacity.

★ 249

Alloy steels. A very comprehensive collection of technical data for the selection of constructional alloy steels has been issued by Samuel Fox.

★ 250

Nuclear spectroscopy. A ' state-of-the-art ' review of the use of crystal spectrometers in the study of nuclear gamma spectra is included in the June issue of the ' Hilger Journal '.

★ 251

German reactor engineering. In a special issue of ' Demag News ', details are given of the nuclear activities of the Demag/Atomics International jointly-owned company Interatom.

★ 252

Welding stainless steel. Uddeholms of Sweden have compiled a manual in English that contains a survey of the welding characteristics of stainless steels and evaluates the usefulness and application of the various welding methods.

★ 253

Double insulation. In the spring edition of Wolf Electric Tool's house journal is an announcement of double insulation for their new 4,000V-tested tools.

★ 254

Prestressed concrete. The ' Reinforced Concrete Review ' for March contains the text of a paper by Mr A. W. Hill reviewing some of the most important issues raised by the new code of practice CP115:1959.

★ 255

Radiation protection. Research and Control have published a catalogue of components, complete assemblies and special materials suitable for protection against ionizing radiations.

★ 256

Ring sealing. Design specifications of standard metal ' O ' rings, developed by Advanced Products for reactor engineering applications, are covered in a recent catalogue.

★ 257

Analogue computers. A well illustrated and detailed handbook of the Pace TR-10 transistorized analogue computer, suitable for operators, has been produced by Electronic Associates.

★ 258

Irradiation facilities. General Electric's integrated irradiation research and development services, including use of their Test Reactor, are available to private industry and governments overseas. The scope of the service is detailed in a recent brochure.

★ 259

Welding electrodes. Various developments of importance in modern welding practice, so far as they concern the design of welding electrodes, are discussed in the May issue of ' AEI Engineering '.

★ 260

Atomic masses. The latest available data on atomic masses have been presented in a recent monograph by the Sandia Corporation. For the sake of consistency, various manipulations have been made to these basic data.

★ 261

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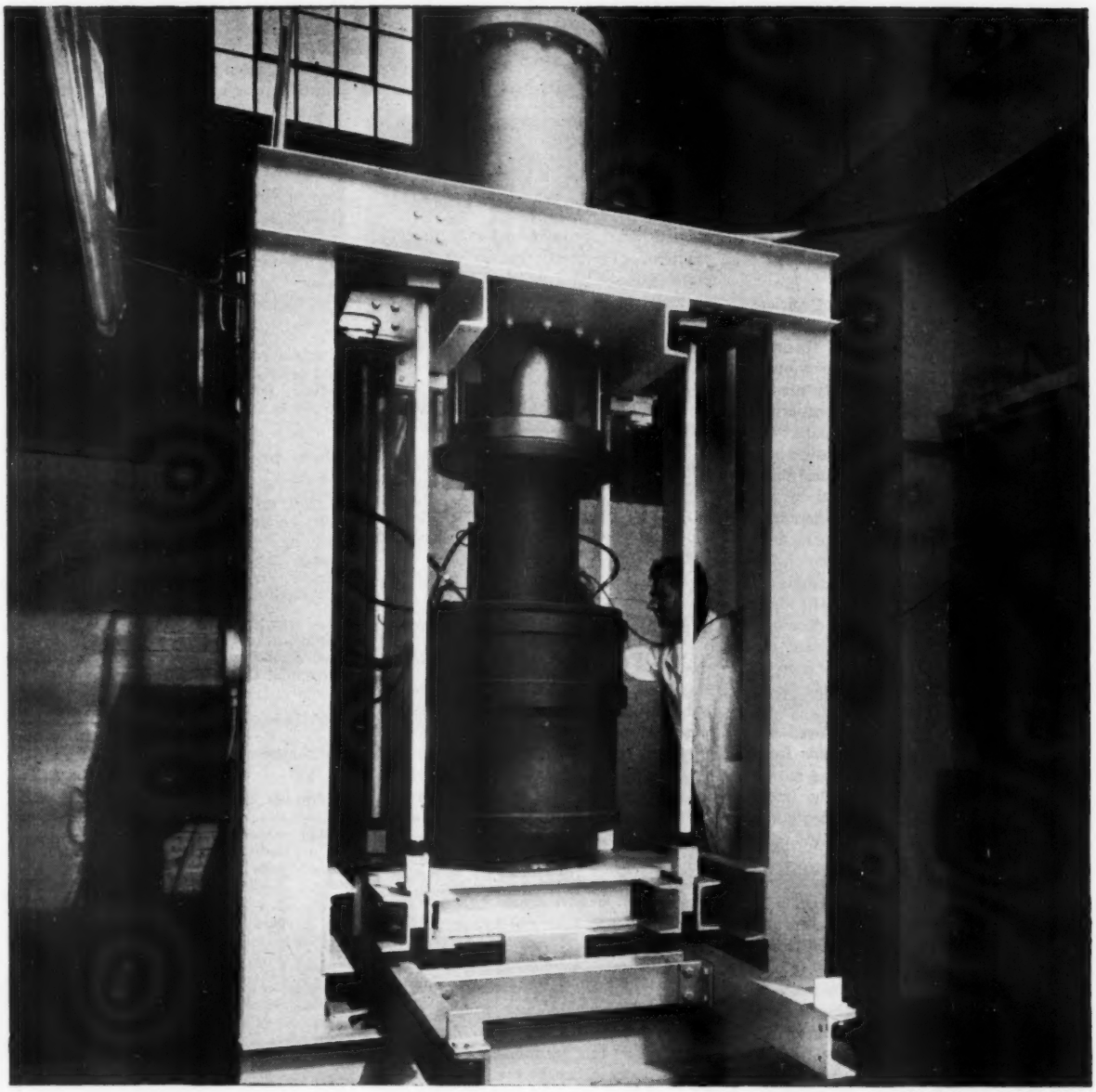

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Book Reviews

Too much theory on nucleon interaction

The most fundamental feature of nuclear physics, the form of the two-nucleon interaction is not yet well known. Theoretical approaches have not yet been made rigorous, nor will they accurately predict the results of nucleon-nucleon scattering. With increasing experimental data, the phenomenological approach has developed, consisting of analysis of the scattering in terms of phase-shifts followed by the use of general theoretical considerations to deduce the form of the interaction. The first 175 pages of the proceedings contain papers dealing with attempts of this kind. For p-p scattering at 310 MeV, the Gammel-Thaler potential deduced in this way gives an excellent fit with the data. A number of fits at different energies using the phase-shifts as variable parameters are given by Breit.

The Japanese group has improved the agreement with the data obtainable from a much less empirical method, using meson theory in the outer region of the interaction. The more recent theoretical approach through dispersion relations is described by Chew.

Knowledge of the two-body force can be used to describe, in some approximation, the behaviour of a simple nucleus, (in the absence of many-body forces), and most of the remaining theoretical papers are accounts of such approximations to calculate nuclear binding energies and account for the results of experiments on nuclear reactions where up to five nucleons are involved. At present the two-nucleon force is not so well known that the existence of many-body forces can be established. The approximation methods described are not essentially new. The advances can be attributed to better knowledge of the two-body force, the use of large computers and increased experimental data.

The papers read by experimentalists were in a minority. They described fairly conventional techniques using a variety of particle detectors and included a good deal of useful data.

It was discouraging, at a conference attended by many experimenters, to note that many of the theoretical papers were written solely for theorists. Exceptions to this were the reviews of Marshak, Massey and Burke, and a paper by Glauber on deuteron collision cross sections at high energies. There seemed to be some reluctance on the part of theorists to indicate what experiments were urgently required. There can be no doubt that more experimental work on the two-nucleon interaction at different energies is needed.

These proceedings give a good account of advances made in this difficult subject up to July 1959, but because these rapid advances are being made it is unfortunate that publication took so long.

J. E. Evans

Nuclear forces and the few-nucleon problem: proceedings of the international conference held at University College, London, July 1959, edited by T. C. Griffith and E. A. Power. Pergamon, Oxford and London, 1960. 2 vols. Price £10.

Pressure vessel firms sparsely represented

This book contains the texts of 22 papers, and the discussions of them, which were presented at an International Symposium organized by the Engineering Department of Glasgow's Royal College of Science and Technology in May, 1960. The papers are presented in four sections having the following headings: 1. Current practice and future trends (four papers from the UKAEA). 2. Design studies and methods of stress analysis (five papers from academic institutions and industrial firms). 3. Shell research—analysis and experiment (ten papers from academic institutions and industrial firms). 4. Engineering design, fabrication, erection and testing (three papers from the UKAEA, The Motherwell Bridge and Engineering Co. Ltd, and Lloyd's Register of Shipping). Section 5 consists of two further papers contributed to the open topic session, and Section 6 contains summaries of the proceedings by four authoritative contributors.

This volume is not intended as a textbook and it cannot give a complete picture of the field embraced by the title. The papers cover a great number of aspects broadly classified as follows: three general papers on the whole field, including one on manufacturing techniques; five papers on the safety philosophy, design, construction, etc., of containment vessels; and fourteen papers dealing with particular aspects of stress analysis and tests with emphasis mainly on the design problems of reactor pressure vessels for graphite moderated gas cooled systems. Unfortunately, only two papers of the 22 are by representatives of pressure vessel manufacturers.

Despite this limited contribution from those concerned with manufacture and the resulting emphasis on theoretical aspects, this book should be studied by all concerned in the pressure vessel field. Even those without a capacity for handling elaborate mathematics should not be deterred as there is ample food for thought elsewhere.

The references given with the papers and also in the discussions are exhaustive and form a useful foundation for detailed study on the particular problems. The discussions are in some cases as valuable as the papers being discussed for many experienced contributors took part.

A. J. Taylor

Nuclear reactor containment buildings and pressure vessels Glasgow Symposium —1960. Butterworths, London, 1960. 572 pp. Price £5.

New books

• *Metal industry handbook and directory* 1961 Iliffe, London 1961 560 pp Price 21s ★ 268

• *Reactors of the World:* second series Temple Press, London 1961 13 cutaway drawings Price 17s 6d ★ 269

• *Physical gas dynamics* edited by A. S. Predvoditelev Translated from the Russian Pergamon, London 1961 183 pp Price 50s ★ 270

• *Techniques of non-destructive testing* edited by C. A. Hogarth and J. Blitz Butterworths, London 1960 216 pp Price 40s ★ 271

• *Progress in nuclear energy, series VI—Biological sciences* Volume 3: the Entry of fission products into food chains; edited by J. F. Loutit and R. S. Russell Pergamon, London 1961 174 pp Price 45s ★ 272

• *International Summer Course in Plasma Physics* Danish Atomic Energy Commission, Risö, November 1960 645 pp Price Kr.60 ★ 273

• *Gases at high densities and temperatures* by Yu. N. Ryabinin Translated from the Russian Pergamon, London 1961 52 pp Price 25s ★ 274

• *Fast reactors* by R. G. Palmer and A. Platt Temple Press, London 1961 93 pp Price 12s 6d ★ 275

• *Thermodynamics;* with quantum statistical illustrations by P. T. Landsberg Interscience, New York and London 1961 499 pp Price 109s ★ 276

• *Radioactive substances in the biosphere* International Atomic Energy Agency, Vienna 1961 43 pp ★ 277

• *Russian-English chemical dictionary* by E. A. Carpovich Technical Dictionaries, New York 1961 Price $12 ★ 278

• *Control of nuclear reactors and power plants* by M. A. Schultz 2nd edition McGraw-Hill, New York and London 1961 462 pp Price £4 17s ★ 279

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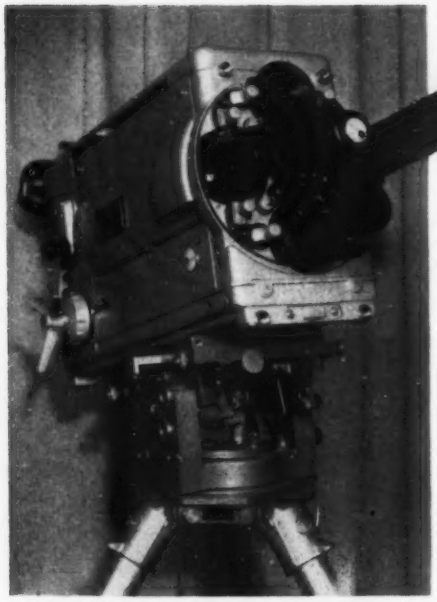

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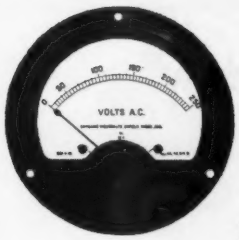

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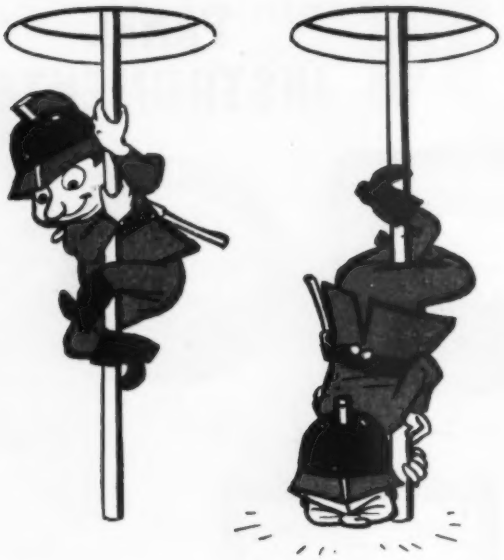

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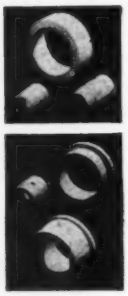

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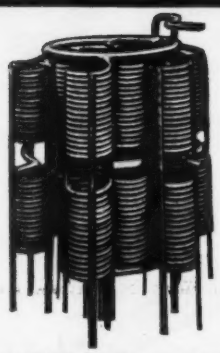

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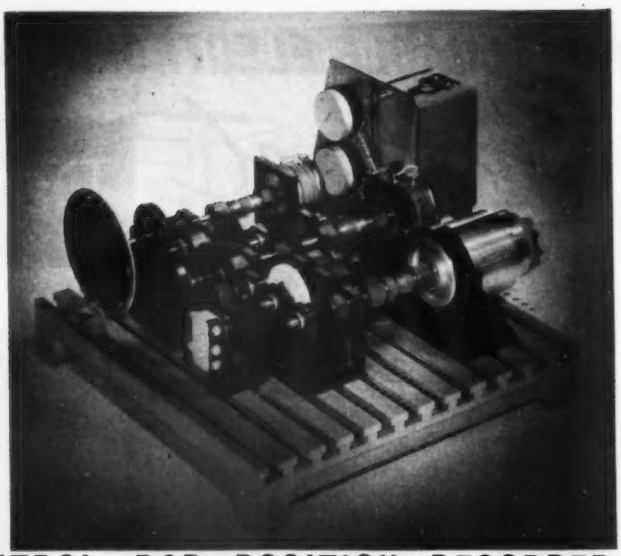

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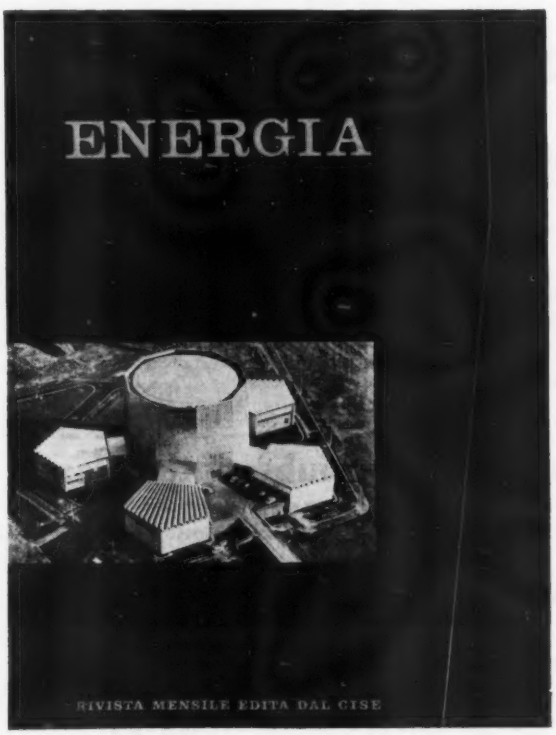

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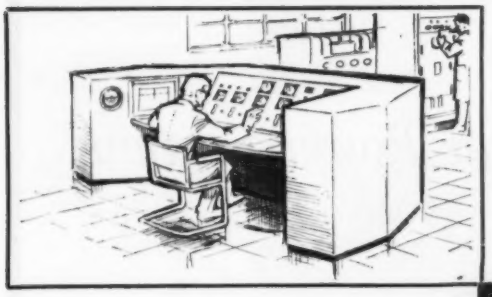

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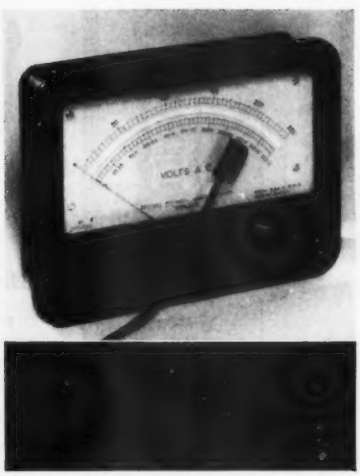

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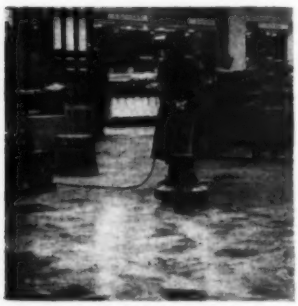

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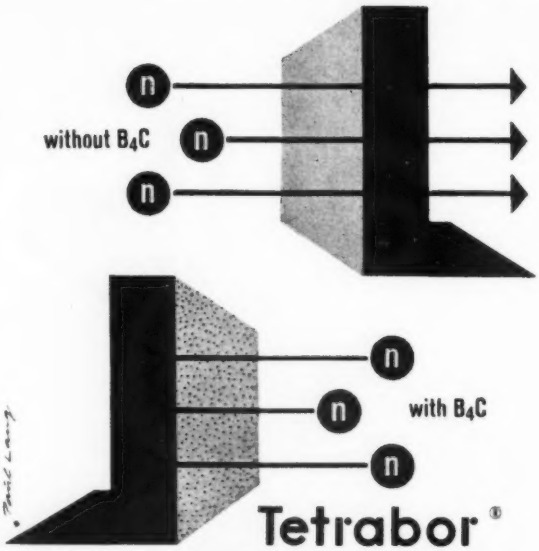

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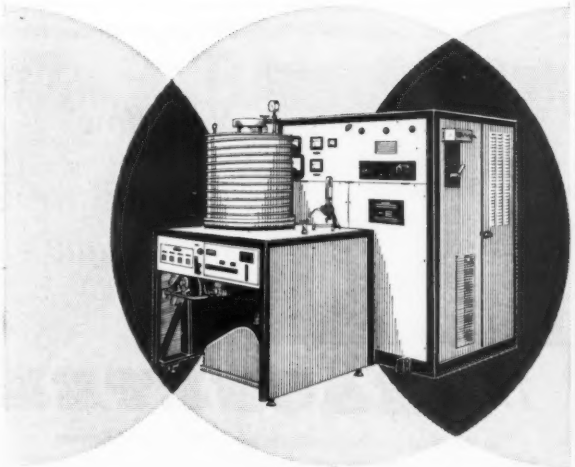

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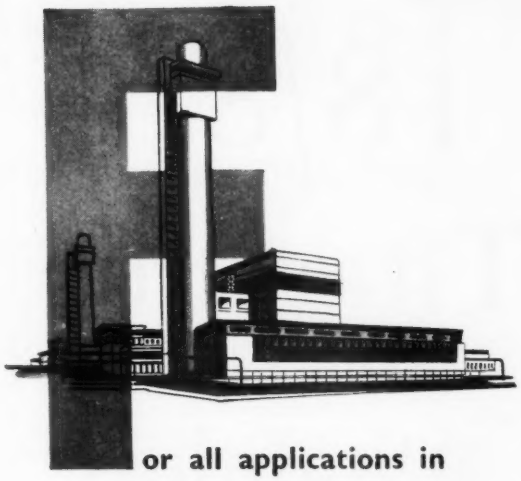

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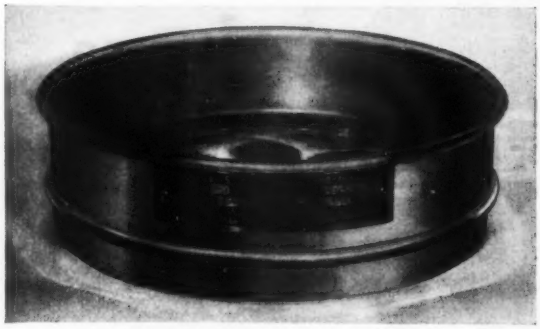

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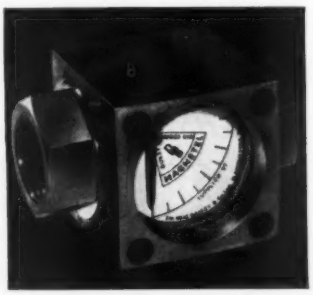

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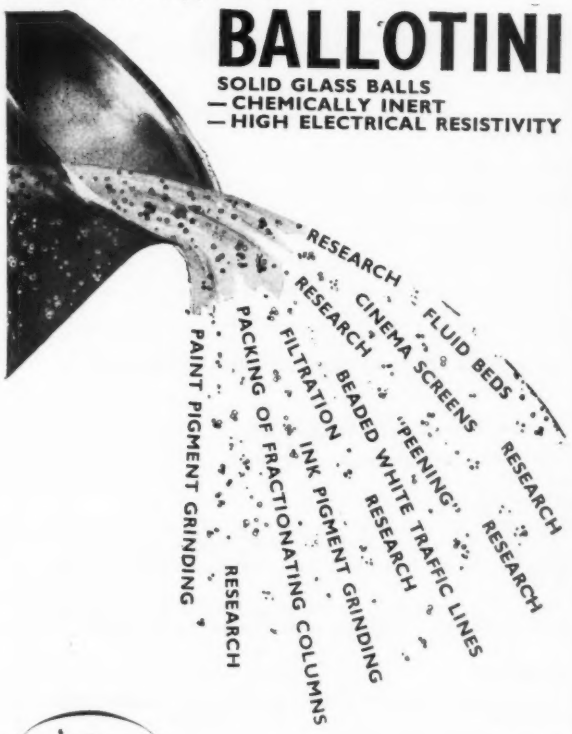

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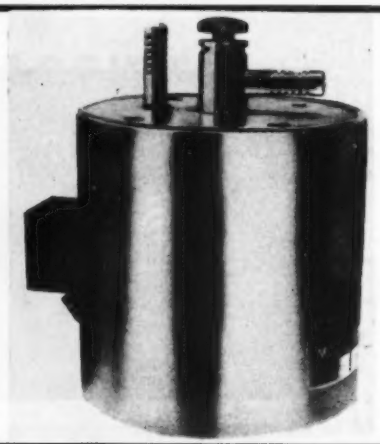

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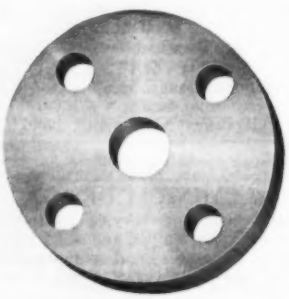

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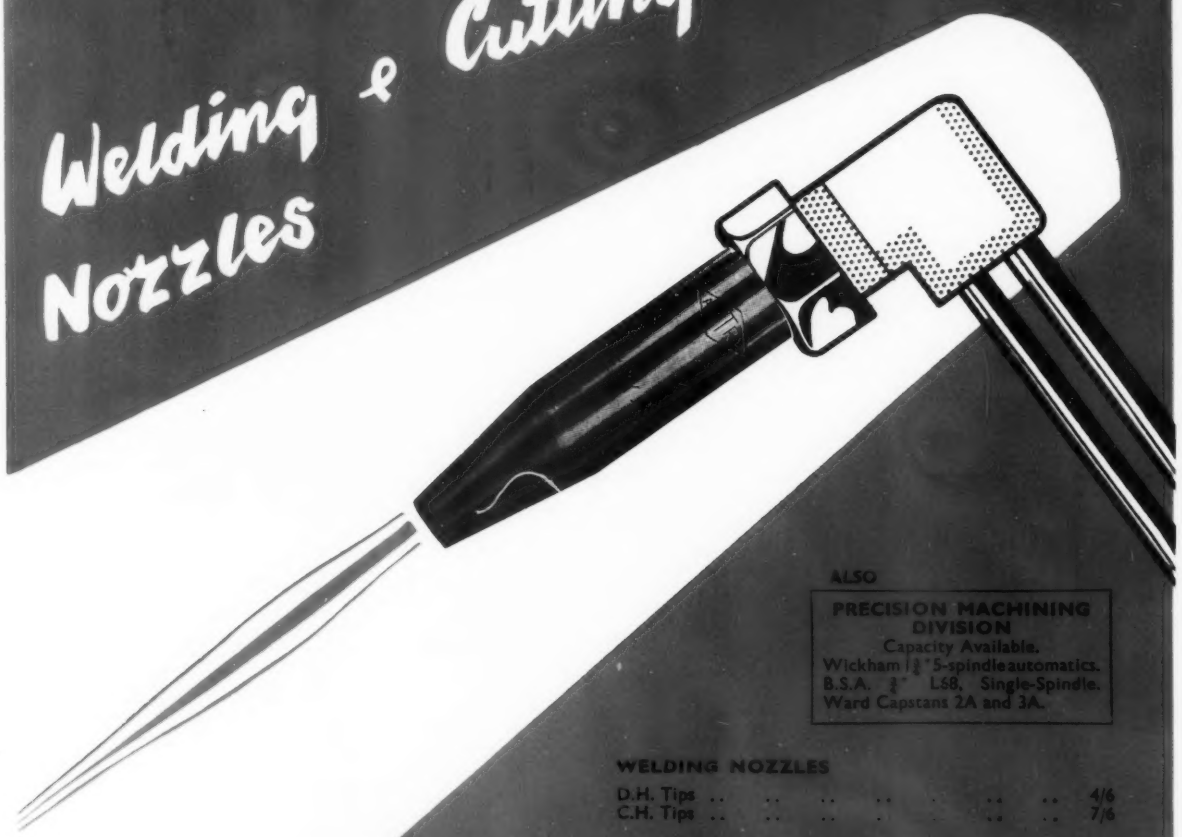

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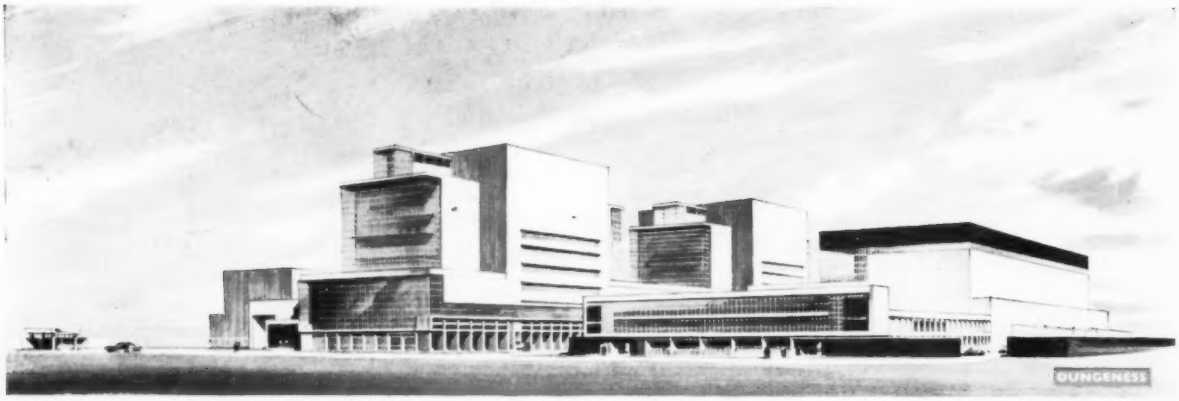

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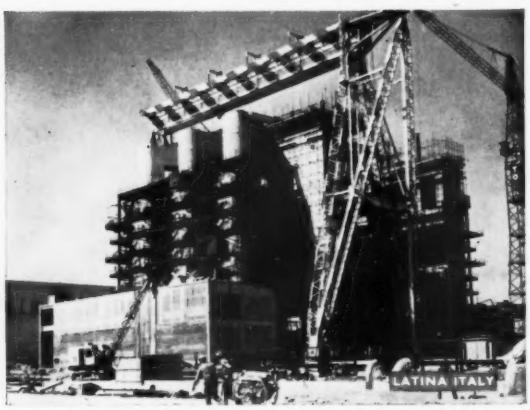
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